

Defensible Methods Of Assessing Fish Habitat: Lacustrine Habitats In The Great Lakes Basin - Conceptual Basis And Approach Using A Habitat Suitability Matrix (HSM) Method

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**DEFENSIBLE METHODS OF ASSESSING FISH HABITAT:
LACUSTRINE HABITATS IN THE GREAT LAKES BASIN –
CONCEPTUAL BASIS AND APPROACH
USING A HABITAT SUITABILITY MATRIX (HSM) METHOD**

by

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ABSTRACT

This report presents a detailed description of the structure and application of a quantitative fish habitat assessment tool for use in evaluating development proposals affecting lacustrine fish habitats in the Great Lakes and beyond. The scientific and regulatory context for the development of the tool are introduced along with a formal quantitative framework developed by Minns (1997) as a basis for assessing net change of productive capacity of fish habitats. Suitability indices are used as practical and pragmatic measures of habitat productivity and weighted suitable areas (area times suitability) are derived as surrogate measure of total productivity of the habitats affected at a development site. A habitat suitability matrix (HSM) model is described for estimating habitat suitability indices along with the rules and criteria that must be applied to allow evaluation of fish habitats. The HSM model uses pooled matrices representing the aggregate habitat preferences of many species by life stage to ensure that the needs of all fishes occurring in an ecosystem or ecoregion are considered. Species requirements are grouped by life stage and ecological groupings according to trophic level and thermal preference. Habitat scenario data sets describe the pre- and post-development conditions at a proposed site as series of habitat patches with characteristics of depth range, substrate type, and cover type. The HSM model generates suitability values for specific combinations of depth, substrate and cover that can be assigned to individual habitat patches. The rules and criteria for preparing the habitat scenario data sets and computing suitability matrices are described in detail with examples. The basis for using this approach in a regulatory context is described as the HSM approach to defensible methods of assessing fish habitat and is intended as an aid to the existing decision process, not as a replacement. Case studies are described as an aid for potential users of this approach. The whole approach has been implemented as an internet website for use by consultants working for developers and by regulatory agents. The scope for application of the approach is outlined along with a discussion of the limits for wise use of the approach. Implementation of the HSM model as a basis for assessing fish habitat represents a first step away from subjective and toward objective assessment tools. It is expected that further research will provide the basis for iterative improvements and enhancements.

RÉSUMÉ

Le présent rapport décrit de façon détaillée la structure et l'application d'un outil d'évaluation quantitative de l'habitat du poisson qui sera utilisé pour évaluer les projets d'aménagement affectant les habitats lacustres dans les Grands Lacs et ailleurs. On y présente le contexte scientifique et réglementaire de l'élaboration de cet outil, ainsi qu'un cadre de travail quantitatif officiel élaboré par Minns (1997) comme base d'évaluation de la variation nette de la capacité de production des habitats du poisson. Des indices de qualité sont utilisés comme mesures pratiques et pragmatiques de la productivité de l'habitat, et des aires appropriées pondérées (aire multipliée par qualité) servent de substitut à la mesure de la productivité totale des habitats touchés dans un site soumis à l'aménagement. On décrit un modèle de matrice de qualité de l'habitat (MQH) qui sert à estimer les indices de qualité des habitats, ainsi que les règles et les critères qui doivent être appliqués pour évaluer les habitats du poisson. Dans le modèle MQH, on utilise des matrices regroupées représentant l'ensemble des habitats privilégiés de nombreuses espèces, par stade de développement, de façon que les besoins de tous les poissons présents dans un écosystème ou

dans une écorégion soient pris en compte. Les besoins des espèces sont groupés selon le stade de développement et le groupement écologique en fonction du niveau trophique et des préférences thermiques. Les ensembles de données sur les scénarios d'habitat décrivent les conditions avant et après l'aménagement d'un site proposé sous forme d'une série de parcelles d'habitat caractérisées par la profondeur de l'eau, le type de substrat et le type de couvert. Le modèle MQH produit des valeurs de qualité pour des combinaisons spécifiques de profondeur, de substrat et de couvert qui peuvent être attribuées à chaque parcelle d'habitat. Les règles et les critères pour établir les ensembles de données pour les scénarios sur l'habitat et calculer les matrices de qualité sont décrits en détail et accompagnés d'exemples. Le fondement de l'utilisation de cette approche dans un contexte réglementaire est décrit (approche MQH); cette approche fournit des méthodes valables d'évaluation de l'habitat du poisson; elle est conçue comme une aide au processus décisionnel existant, et ne le remplace pas. Les études de cas sont décrites pour aider les utilisateurs potentiels de cette approche. L'ensemble de l'approche constitue maintenant un site web à l'intention des conseillers collaborant avec des promoteurs et des agents chargés de la réglementation. On présente la portée de l'application de l'approche, ainsi qu'une analyse des limites en vue d'une utilisation rationnelle de l'approche. La mise en œuvre du modèle MQH comme base d'évaluation de l'habitat du poisson représente la première étape du passage d'outils d'évaluation subjectifs vers des outils objectifs. Les travaux de recherche complémentaires serviront de base à la poursuite de l'amélioration et de l'actualisation de la méthode.

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1.0 INTRODUCTION

Human development activities in aquatic ecosystems can alter, disrupt, or destroy fish habitat. Assessing the induced changes in fish habitat features and then detecting responses in fish communities are scientifically complex problems (Minns *et al.* 1996). There are too many separate development activities being proposed every day, too few people in habitat management agencies for every proposed activity, and too much time would be required to complete a thorough assessment in every instance. Quantifying changes in habitats and the effect of those changes on fish populations is costly and time-consuming.

Assessment of *proposed* development activities also poses a major conundrum. Complete studies of human development, or ecosystem restoration activities, requires both pre- and post-project data. This comparative approach cannot be followed for most projects as the decision to allow the activity must always precede the post-development assessment and, given human nature, projects are rarely undone even when post-project assessment shows damage has occurred. As an alternative, experimental studies of classes of development or restoration activities could be a useful guide. Unfortunately, few such experiments have been performed. There have also been few efforts applied to scientifically evaluate the impact of earlier development activities as a guide to assessing proposed changes (Cudmore-Vokey *et al.* 2000).

In the absence of experimental studies or the opportunity to gather comparative evidence, assessment methods must be sought that make best use of the available scientific evidence. Such methods will provide the most defensible estimates of impact and hence as sound a basis for decision-making as is achievable with existing science. Of necessity, these methods will have to rely on predictive models. Such models are amenable to scientific testing and models can be modified or replaced as new knowledge arises. These habitat assessment and evaluation tools can be collectively described as 'scientifically defensible methods.'

The purpose of this report is to present a conceptual basis of the 'Habitat Suitability Matrix' (HSM) method and software used to assess development projects affecting lacustrine fish habitats in the Great Lakes basin. HSM is based on a prototype described by Minns *et al.* (1995a) for coastal headlands and islands in the lower Great Lakes. The approach has been implemented as an interactive software application which will soon be available (estimated date, April 2001) to the public on the internet (see <http://www.bio-software.com>). This report describes in detail the approach taken to assessing fish habitat in lacustrine ecosystems using scientifically defensible methods. The report also gives a step by step rationale and guide for potential users of the software. However, it is not intended as a software user guide.

The scope for application of this current version of the approach is as follows:

- It is mainly intended to be used to assess development projects occurring in the Great Lakes and other large inland lakes in the Great Lakes basin.
- With due attention to the fish species being considered and the landscape contexts, this version should also be applicable to other large lakes and smaller inland lakes throughout Ontario.
- There is also a similar database for fish species occurring in lacustrine habitats in Newfoundland and Labrador. It is not described here but the approaches available for Great Lakes basin applications is transferable.
- It is primarily intended for the assessment of development activities involving physical alteration of lacustrine habitats such as shoreworks and coastal protection; harbours, piers, and docks; or creation of promontories and islands.

- This current version is not intended for use for assessing development activities affecting streams and rivers – planned later versions will address these activities.
- Completion of an HSM-based assessment does not, by itself, constitute completion of the review, assessment, and decision processes undertaken by Fish Habitat Management staff or their delegated authorities, but can constructively contribute to the fulfilment of those processes as required under the Fisheries Act and in compliance with the federal Policy for the Management of Fish Habitat.

This introduction continues with a review of relevant legislation and policy, a brief description of the net change equations under-pinning the approach, a review of literature regarding other approaches to assessment and the origins of some aspects of HSM approach to developing a scientifically-defensible methodology, a summary statement of the principles and assumptions that are the foundation of the approach, and finally, an outline of the contents of succeeding sections.

1.1 Legislative and Policy Background

The federal government of Canada has specific legislation, the Fisheries Act, and policy, The Policy for the Management of Fish Habitat, that provide the primary reference points for assessing proposed changes to fish habitats and for deciding if they are permissible. These instruments are administered by Fisheries and Oceans Canada. Both implicitly have quantitative elements indicating the potential for numerical assessment criteria to be used in regulatory decision-making.

The original Fisheries Act dates from Confederation in the mid-19th century. The Act provided a means for managing and protecting Canada's fishery resources and covers all fishing areas, seas and inland waters. The Act is binding on all levels of government in Canada and supersedes provincial legislation. Habitat and pollution provisions were added to the Act in the 1970s. Section 35 deals specifically with habitat protection. Section 35(1) is a general prohibition forbidding the 'harmful alteration, disruption or destruction' (HADD) of fish habitats. Under Section 35(2) the Minister of Fisheries and Oceans can authorize a HADD allowing a project to avoid violating 35(1). Securing an authorization is not mandatory but large penalties can be imposed on those causing a HADD without prior ministerial authorization. Section 35 is implicitly quantitative as the decision that an activity affecting fish habitat is harmful implies there are thresholds or gradients of negative impacts on fish productivity.

In 1986, DFO issued its Policy for the Management of Fish Habitat. The Policy recognized the essential role of habitats in maintenance of healthy, self-sustaining, productive fisheries and reaffirmed the government's commitment to managing and protecting them. The guiding principle of the Policy is 'no net loss of the productive capacity of habitats'. Consistent with the Fisheries Act, productive capacity is defined as 'the maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms upon which fish depend'. Three policy goals provide the basis for achieving net gain: conservation of existing habitats, restoration of damaged ones, and development (or creation) of new ones. The Policy also addresses the need for integrated management of fish habitats to support fish productivity and fisheries in the context of other ecosystem uses and requirements. The policy is also implicitly quantitative as determining whether or not changes to fish habitats achieve a net gain or loss requires the comparison of measures of productivity estimated with and without the proposed change.

In practice, the habitat provisions in Section 35 of the Act and the Policy are linked. First, proponents are directed to avoid unacceptable HADDs. Next, proponents are encouraged to seek

mitigation actions that prevent any HADD and hence avoid the requirement for an authorization. Finally, if mitigation fails or is insufficient to prevent a HADD, an authorization is required and proponents are then obligated to develop a set of compensatory actions that will result in an overall net gain, or at least no net loss (NNL). There are several types of potential compensation: combinations of habitat creation or productivity enhancement, like-for-like or unlike, within the same or different ecological unit, and use of rare measures, such as artificial production. Like-for-like habitat compensation within the same ecological unit is the most preferred type (DFO 2000).

1.2 A Quantitative Framework for Measuring Net Change

Minns (1995a, 1997) presented a quantitative basis for assessing net gain or loss of natural productivity of fish habitats. The equations given in those papers provide the basic framework used to compute net change with the HSM approach. Net change is computed as follows (equation 15 in Minns 1997):

$$\Delta P_{NOW} = [p_{MOD} - p_{NOW}] \cdot A_{MOD} - p_{MAX} \cdot A_{LOSS} + [p_{COM} - p_{NOW}] \cdot A_{COM}$$

where,

- ΔP_{NOW} = net change of natural productivity of fish habitat
- A_{LOSS} = Area of habitat lost due to development activity
- A_{MOD} = Area modified, directly and indirectly, as a result of the development activity
- A_{COM} = Area created or modified elsewhere to compensate for the development activity
- p_{MAX} = Maximum potential unit area productivity rate (or productive capacity)
- p_{NOW} = Present unit area productivity rate
- p_{MOD} = Modified unit area productivity rate in affected areas
- p_{COM} = Compensation unit area productivity rate in affected areas.

This equation can be generalized for a habitat area consisting of a mosaic of habitat units with varying attributes and unit area productivity rates. The maximum productivity rate, p_{MAX} , is set to a value of 1 and all others are proportions of that reference value. Where multiple habitat units are involved, the highest maximum productivity rate is set to one and all other rates, maximum or otherwise, are expressed as proportions. There is no single variable that measures the productivity rate of a unit of fish habitat. A variety of metrics might be used to infer the overall productivity per unit area, e.g., fish biomass, fish productivity, benthic biomass, species richness of the macrophyte or zooplankton communities, or an index of biotic integrity. To compute a proportional productivity index for various sites or habitat types, data on one or preferably several metrics combined would be rescaled using the representative portion of the range. For example, Minns et al (1994) used the 95th percentile of various metrics to define the upper bounds for indices used in developing an index of biotic integrity.

The division of areas affected by a development project into loss, modified, and compensation categories are implemented in the HSM approach and provides a straightforward means of appreciating the scope of impacts attributable to a development activity.

Successful implementation of a scientifically-defensible method like HSM hinges on developing a method of estimating unit area productivity rates, or an equivalent, surrogate metric such as habitat suitability indices. Pragmatic derivation of indices acting as surrogates for habitat productivity will have to continue as the norm until more explicit, defensible methods of accounting for productive capacity have emerged.

Various properties of this mathematical scheme were described by Minns (1995a, 1997). The key property with respect to assessing development activities are the distinctions among absolute loss where habitat is destroyed, absolute gain where habitat is created, and relative changes in modified or enhanced habitats. This property provides an *a posteriori* rationale for the compensation multiplier rules of thumb that have often been developed in the past. For example, if a development destroys one unit of habitat with a proportional productivity rate of 1, improvement of productivity rate from 0.4 to 0.6 will require that five units of habitat be modified to achieve no net loss. In simple terms, the proponent is charged for losses at the maximum productivity rate and for modification at the difference of future and current rates, and is credited for improvements due to compensation at the difference of future and current rates.

1.3 Previous Quantitative Assessment Schemes

There are relatively few quantitative schemes for use in the assessment and management of development activities affecting fish habitat. The Habitat Evaluation Procedures (HEP) and associated Habitat Suitability Index (HSI) modelling approaches developed by the U.S. Fish and Wildlife Service (USFWS 1981, Terrell *et al.* 1982, Terrell 1984) in the late 1970s and early 1980s contributed significantly to the conceptual evolution of the HSM approach. The site-assessment scheme developed by Christie (1982) for Ontario Hydro to assist with the evaluation and selection of sites suitable for nuclear power plants on the Great Lakes provided much stimulation for the design of model described here. Concepts embodied in the gap analysis process (GAP) for terrestrial ecosystems (Scott *et al.* 1993, Jennings 2000) provided additional stimulation.

Christie (1982) compiled an extensive database characterizing various life history and habitat preference characteristics of Great Lakes fishes and used it to examine the database's aggregate power to predict presence-absence of particular species at specific locations. Overall, his scheme performed quite well when applied to sites where fish community survey data were available. The scheme was a descriptive rule-based approach with minimal computation needs. While it showed the potential power of life history and habitat attributes of species, no attempt was made to directly assess the suitability of specific habitat areas. Grandmottet (1983) and Degiorgi and Grandmottet (1993) laid the groundwork for a life-history habitat attribute-based approach to assessing fish habitat which is providing much stimulus for stream habitat classification and assessment in France. These studies showed how species-based assessment of preference can provide a means for discriminating among habitat types in freshwater ecosystems.

1.4 Content of this Report

This report builds on the preliminary work reported by Minns *et al.* (1995a). In section 2, the framework for this defensible method, a Habitat Suitability Matrix (HSM) method, is presented with detailed descriptions and examples for each step. In section 3, preliminary guidelines are presented for the collection and organization of all information required for successful application of the approach. In section 4, a pair of case studies is presented illustrating the application of the HSM-based assessment model to development projects affecting fish habitat. In section 5, a review and analysis of conceptual foundations of the methodology is presented, identifying current limitations of the approach and potential future scope for extension, elaboration, and application of the framework.

2.0 FRAMEWORK FOR ASSESSING FISH HABITAT

Minns *et al.* (1995a) presented a prototype for the present approach to assessing the potential impact of human development activities on fish habitat in lakes. *The essence of the approach is the idea that the habitat preferences of individual fish species and life stages can*

be quantified and aggregated into habitat suitability indices that in turn can be used as surrogate measures of fish habitat productivity. The derivation and application of habitat suitability indices has been embedded in an assessment framework, known as Defensible Methods of Assessing Fish Habitat, and implemented in an software product known as the Habitat Suitability Matrix (HSM) method.

The implementation of the framework is founded on and guided by a basic set of principles and assumptions. These principles and assumptions need to be recognized from the outset.

2.0.1 Principles

- Use assemblages not single species - Development sites should be assessed in terms of the habitat requirements of all fish species potentially using the area. Assessments based on the requirements of single species are unlikely to represent the needs of the whole assemblage. Experience from ecosystem science indicates that groups of species have linked requirements. For example, a top predator has habitat and prey needs. The habitat needs of the prey must be considered in efforts to sustain predator populations. This principle is consistent with the ecosystem approach which is widely espoused for the management of freshwater and other ecosystems in North America and elsewhere (Allen *et al.* 1993; Minns 1995b).
- Use surrogate physical/chemical indicators of fish productivity - Direct measures of fish productivity are costly and time-consuming to obtain. In the context of site-level development assessments, a measure of fish productivity might be possible for the pre-development scenario. However a prediction for the post-development scenario will still be needed as authorization to proceed must inevitably precede project implementation and attainment of post-development conditions. This is not to imply that all biological evidence should be ignored. However, site-specific assessments of the biological community undertaken in support of applications for development approval rarely include adequate data. Assessments consisting of a few site visits with limited sampling cannot possibly provide an adequate appraisal of year-round and diurnal use of habitat by the complete fish assemblage and the other organisms whose productivity supports that of fish.
- The science is incomplete - Fish habitat science is incomplete and will remain so for the foreseeable future. Knowledge of the details of the life histories, habitat requirements, trophic interactions of many fish, and other biota present in freshwater ecosystems, is poor or extremely limited. There are on-going efforts to expand fish habitat science though there are many types of ecosystems and development activities to be considered (cf Lester *et al.* 1997; Levings *et al.* 1997). Decisions will still be made despite the incompleteness of the science. It is impractical to delay decision-making for any development activity because of a lack of knowledge as long as there is no societal commitment to funds the responsible agencies to fill those information and knowledge gaps. Existing conceptual understanding and data must be used in a scientific manner to provide the best possible guidance and assessment.
- Precautionary Principle - Where uncertainty is very high for certain classes of development or classes of habitat, the Precautionary Principle should apply (Garcia 1994; Richards and Maguire 1998). The default conclusion should be that the proposed activities will cause an unacceptable net loss of productivity of fish habitat and that the project should not proceed in the absence of further studies to reduce the uncertainty to acceptable levels. Application of this principle requires a careful exercise of judgement taking into account the size and/or significance of the fish habitat productivity at risk.

- Quantitative process - Habitat assessment is a quantitative process involving an integrated consideration of the quantity and quality of constituent habitats. Assessment of net gain or loss as described in the Policy is only possible if a quantitative approach is used (Minns 1995a, 1997). The steps involved in the development of quantification force the assessment process to become transparent and assumptions are made explicit.
- Affected areas only - Only habitat areas affected, directly or indirectly, by a proposed development should be included in a site assessment. If larger frames of reference are adopted for an assessment, it is easy to generate an analysis where the relative or proportional impact of any site-specific development will appear to be minimal or trivial. This situation might be less of a problem if area fish habitat management plans as envisaged in the Policy were in place. Such plans would make explicit links between fish community and fishery objectives and identify the quantities and qualities of habitats needed to sustain those objectives. With such a plan as a reference point for evaluation of site-specific assessments, decision-makers would perhaps have more leeway and flexibility when considering the significance of expected impacts at particular sites. Meanwhile, in the absence of such plans, the only prudent course is to limit the assessment to affected areas, thereby conforming to the Precautionary Principle.
- Equal treatment of pre- and post-development scenarios - The same criteria (habitat features, fish assemblage, weights, etc.) should be used for both pre- and post- development scenarios at a site. Each site-specific assessment should be judged in the same context with the same fish community and fishery objectives as a reference point. If, for instance, a proponent were able to assess the pre-development scenario with one set of objectives and the post-development one with another set, this would create distortions where habitat favourable for one group of species would be replaced with habitat suitable for another group of species. Certainly, there should be some leeway for fish community and fishery objectives to evolve over time in response to increased understanding, changing fishery priorities, etc., but site-specific development activities should not be used as an instrument of such an evolution. Such an approach would be irresponsible and would likely encourage opportunism.

2.0.2 Assumptions

Given the embryonic status of quantitative fish habitat science, a number of assumptions are necessary to facilitate the development of a quantitative assessment scheme. None of these assumptions has been adequately tested or challenged but they represent a minimum set. While for particular life stages of some fish species there may be evidence that violates these assumptions, for the majority of species our knowledge base is minimal. As the purpose here is to provide some improvement over the subjectivity of decision-making now in place, these assumptions are a minimum requirement to allow effective scientific use of what little information is available. It is expected, hoped even, that future scientific research will provide evidence that will confirm, enhance or supplant this initial effort. The key assumptions are as follows:

- Suitability as a surrogate for productivity - The approach taken here assumes there is a simple one-to-one correspondence between suitability indices, scaled between 0 and 1, and the fish productivity of habitats. Alternative assumptions would require that non-linearities in habitat-productivity relationships and life-stage bottlenecks be fully known (cf Minns *et al.* 1996). Until such non-linearities are better understood, the linear assumption is the prudent course.

- **Suitability criteria** - The analysis of suitability as a measure of maximum potential natural productivity, or productive capacity, only considers three habitat features: depth, substrate, and vegetation cover. While other features of cover have been noted (Lane *et al.* 1996a,b,c) as being important for various species and life-stages, there is little evidence that habitat mapping is ever of sufficient detail in lacustrine environments to justify their inclusion in this version. However, work is currently being done to expand cover preferences to include non-vegetated cover. Suitability indices based on physical habitat features are most likely reflective of the maximum potential productivity or productive capacity and hence net gains will be largely achieved by shifting habitat conditions toward those with higher intrinsic productivity values.
- **Condition index** - Suitability indices may be modified to reflect current, realized natural productivity through the use of a condition index. This condition index is scaled between 0 and 1, and reflects an assessment of the impact of other non-physical habitat variables such as nutrient, contaminant, and acidity status in water and substrates, the presence of health impairments in the fish due to human activities, current patterns and velocities, and thermal habitat. For example, if water quality at an urban habitat is currently impaired by poorly managed stormwater flow, a condition that will be fixed as part of a proposed habitat alteration, the condition factor for affected habitat might be set below 1 in the scenario describing present conditions and set at 1 for the post-development scenario. Another example describes the use of the condition index in relation to altered shoreline exposure later in the report, section 3.1.2, and in Appendix A.
- **Mathematically simple** - All habitat features are treated independently in the calculation of suitability. Simple addition and multiplication are the means by which elements are linked.
- **Relative scaling** - All suitabilities can be expressed on a relative scale of zero to one (0-1) allowing weighted suitable areas to be computed. This in turn allows suitable areas to be computed as the product of area, suitability, and condition then summed across all affected areas in scenarios.

2.1 Overview of Habitat Suitability Matrix Method

The assessment framework has three main components: **Definition, Analysis, and Reports** (Figure 2.1.1). Users provide the necessary definition information, run an analysis, and then select from among report options to obtain a set of results to assess expected net gain or loss of productivity of fish habitat. Habitat scenarios for pre- and post-development contexts are prepared as part of the Definition component and must meet a set of basic requirements before the Analysis component can proceed. A number of decisions about the membership of the fish assemblage being assessed and the linked fishery-habitat management objectives at the site and in adjacent areas must also be settled during completion of the Definition component.

The Definition component has four modules: Location, Species Groups, Scenarios, and Habitat Variables (additional modules may be added in the future covering topics such as project documentation and statistics on the history of the definition). The Analysis component is where the analytical model is specified, the integration of inputs and reference databases, and the calculation of results is performed. The actual mechanics of the analysis are not seen by or accessible to the user of the software but all the details of how the calculations are performed is described in detail below. The Reports component provides several options for exploring the many layers of calculations and intermediate results that together produce the integrated results for an assessment of net gain or loss. Data in results tables can be copied via a clipboard to spreadsheets or they can be exported as files. In addition, results tables currently opened in the

Reports component can be printed. A standard print-out gives a detailed statement of the decisions made in setting up the definition and a subset of results judged to be a minimum set for appraising a development/restoration referral.

2.2 Definition

Several linked steps make up the Definition component. Before the formal definition phase can proceed, preparatory discussions among proponents, regulatory agencies, and other stakeholders are advised to build a consensus on the fishery and fish habitat objectives as a context for the assessment. The formal steps include:

- (a) Location where a biogeographically appropriate species list is selected;
- (b) Groups where the species are assembled into groups using agreed criteria involving both ecological or user-defined principles. Group weights are assigned in this step indicating the relative importance or significance attached to different groups of fish species;
- (c) Scenarios where a series of one or more physical habitat scenarios for an area assessment are brought into the definition; and
- (d) Fish Habitat Features are first used to select and weight the fish habitat features to be used in the assessment. Later, after scenarios have been imported, input, internal and reporting habitat categories must be reconciled.

Choices made in the Definition component strongly influence the results of the analysis and must be accompanied by supporting justification and documentation as determined by regulatory authorities. The process leading to these choices must be clearly documented in the final assessment report.

2.2.1 Location Species List

Selection of a species list for the site is an important step in the Definition component. The species assemblage chosen shapes the context of the analysis. If the habitat preferences of coldwater piscivores are the only ones considered, habitats important to warmwater and coolwater species will be devalued in the analysis. Hence, the species list should not be based solely on the detection of species at or in the immediate vicinity of the proposed development site although any species so reported should be included. Surveys with limited spatial or temporal extent are unlikely to secure a complete list. Pre-existing compilations provide a more reliable basis for building a list. Complementary approaches are recommended for Great Lakes sites and inland lakes in the Great Lakes basin or the rest of Ontario.

On the Great Lakes, the complete species list reported should be used. There is no need to worry about including species which spend all or some life stages confined to lotic habitats. The species list is filtered by life stage and any confined exclusively to streams and rivers are excluded from the analysis. Dr. E.J. Crossman and his M.Sc. student, Becky Cudmore, at the Royal Ontario Museum (personal communication) have been compiling a complete species listing for all of the Great Lakes (Cudmore-Vokey and Crossman 2000).

In individual inland lakes, species lists tend to be shorter than the list reported for their secondary or tertiary watershed as a whole (Minns 1989). Various evidence points to relatively high levels of species turnover in inland lakes and streams, particularly among the smaller species (Magnuson *et al.* 1994, He and Kitchell 1990, Robinson and Tonn 1989, Jackson and Harvey 1997). Therefore it is recommended, as a starting point, that tertiary watershed species lists be used for habitat evaluation in all lakes occurring in each watershed. The species on a watershed list can be pared away where particular circumstances justify it. For example, while lake trout may be present in a watershed, only lakes with an oxygenated hypolimnion during the summer will be capable of supporting them.

There are several sources of reported watershed species lists (Minns 1989, Minns and Moore 1995, Doka *et al.* 1997) and reliable maps of most fish species distribution are provided for Ontario in Mandrak and Crossman (1992). A comprehensive national tertiary watershed database is being prepared as a standardized source for HSM applications (Mandrak and Minns, unpublished material).

The creation and editing of a location species list is undertaken in a separate module of the software application. A library of species found in the Great Lakes, other large lakes, tertiary watersheds, and other significant categories will be available as part of the software application with a georeferencing module to allow users to determine the watershed code from latitude and longitude coordinates.

Users need to ensure that the reviewing agencies agree with the species list selected for a location. Arbitrary lists and lists containing very few species will produce spurious or questionable results.

2.2.2 Assembling Fish Species Groups

There are many bases on which fish species might be grouped. Species might be grouped on the basis of their usefulness to people (sport vs. commercial, game vs. pan vs. forage, etc.). However, since the objectives of fish habitat management are closely aligned to those of ecosystem management, ecological attributes probably have more relevance. Fish are often grouped according to their thermal preferences (warmwater, coolwater, and coldwater) and food habits (piscivore, omnivore, detritivore, herbivore, invertivore, etc.). The spawning guild (Balon 1975) of the species may play a major role and might be used as a grouping criteria. Taxonomy might also be used to form groups although they will often align with other attributes. These attributes have been tabulated along with other life style characters to assist the formation of fish groups.

The presence-absence of piscivory is one of the most important attributes given the role of top-down role predators have in shaping the particle-size spectrum of biomass and production. Different sites will have different thermal regimes and the fish groups will play an important role once species' group weights are applied. Many exposed sites on the north shore of Lake Ontario are affected by upwellings during the summer, bringing coldwater species inshore. Those species may be an important part of a nearshore fishery and may be weighed more heavily in the analysis of habitat alterations. Elsewhere, warmwater species may be more favoured.

Additional criteria for the creation of species groups have been established: taxonomic groups at the genus and family level, and life history attributes including size and age at maturity and at maximum sizes. These may be used to divide the species list into a workable set of groups reflecting the fisheries objectives at that location. Care must be taken to avoid creating groups with the same species occurring more than once as exclusivity cannot be guaranteed and the results are compromised.

Users may choose to create arbitrary fish groups but need to make sure the reviewing agencies agree with the group assignments. If arbitrary groupings of fishes are created, there should be further investigating by the reviewing agency to ensure the groups do not induce a flawed analysis. For example, mixing coldwater and warmwater species in the same group might tend to undervalue habitats preferred by coldwater species.

2.2.3 Fish Habitat Criteria

In the prototype version of HSM method (Minns *et al.* 1995), there were habitat suitability criteria based on:

- (a) the spawning and adult habitat requirements compiled by Christie (1982);

- (b) a model predicting aggregate fish attributes on the basis of vegetation cover (Randall *et al.* 1996) for transects sampled at the 1.5 metre contour, and
- (c) suitabilities extrapolated to other depths using results presented by Keast and Harker (1977).

Some of these criteria proved difficult to expand to a basis for a fuller implementation of HSM. Christie (1982) had compiled a large amount of habitat use information for species occurring in the Great Lakes but often the categories for various habitat features were too coarse for practical use in shallow nearshore waters. It is expected that work, such as that by Randall *et al.* (1996), will eventually provide alternate models linking fish assemblage attributes to habitat features in the future once the range of habitat types is more comprehensive and the means of generating suitabilities from predictive modelling is established. Systematic comparative evidence of how fish assemblage attributes vary with depth in lakes is not very common. Such evidence will be needed if more sophisticated suitability models are to be developed.

To overcome the limitations encountered in the prototype, a standardized process of assembling a summary of habitat preferences by life stage and species was established. The habitat features were limited to depth, substrate, and cover (mainly vegetation). This process relied on review and summary of available literature followed by expert peer-review of the results and publication. At present there are three habitat criteria recommended for HSM-based analyses in Great Lakes basin lakes: spawning, young-of-the-year (YOY), and adult habitat requirements based on the data sets compiled by Lane *et al.* (1996a,b,c). The categories used for adults differed from those used for spawning and YOY stages in the Lane *et al.* reports. Those differences have now been eliminated and a revisory for the Lane *et al.* databases is being prepared. These qualitative indications of habitat preference provide a basis for a quantitative suitability measure when combined for groups of species. For each species and life stage, suitability matrices are computed for combinations of depth, substrate, and cover categories.

Databases for stream habitats in the Great Lakes basin and lake habitats in Newfoundland and Labrador has been completed. Extensions of HSM method to those contexts are under development and will be reported elsewhere. Lacustrine databases for British Columbia, the Prairies, and the North (NWT and Nunavut) are under development and will be added later, widening the geographic scope of applications.

2.2.4 Group and Criteria Weights

For the analysis to produce an integrated assessment of net gain or loss, weights must be applied to both the fish groups and the life stage habitat criteria. The weights are proportions whose sum across groups or criteria must equal one. For example, if the species list is divided into six groups according to thermal preference and the presence-absence of piscivory, each group could be assigned the same weight of 1/6th. This indicates that all three thermal groups are given equal weight and that piscivores are weighted equally to non-piscivores. These weights eliminate any differences in the number of species contributing to each group. Thus, if 5 piscivores form one group and 25 non-piscivores form another group, one composite suitability matrix is compiled for each of the groups and the external user-supplied weights determine their contribution, not the number of species. Setting the values of the weights requires a reasoned assessment of the ecosystem conditions, the fish assemblage and fisheries, and fishery objectives in consultation with the appropriate management agencies and the process is described in more detail in section 3.2.4.

2.3 Habitat Scenarios

2.3.1 Data Specifications and Format

The scenario data files for HSM applications have a simple text-based, comma-delimited format. Users may derive their scenario information from more complicated application software but it is required that these applications export their results in the standard format. The data files contain three main types of record: titles, directives, and habitat units (Table 2.3.1). The title records allow the user to keep track of different scenarios as various options are considered. The first title record provides the name used in HSM to track a scenario. The directives records provide information about the habitat unit type, i.e. area, volume or length. Also, under directives, the units record gives the measurement scale, e.g. metres squared. The order record provides the order of variables on the habitat unit records. The unit identifier allows the user to keep track of habitat units on maps and to compare the same unit in pre- and post-development scenarios. The area associated with a particular ID should preferably be the same in both cases when dealing with habitat units that are modified as this will facilitate more detailed comparisons.

2.3.2 Scenario Options

The HSM method can be applied in two distinct ways: (1) to compare pre- and post-development scenarios and compute net gain or loss of suitable habitat, and (2) to provide an estimate of suitable habitat supply or to map relative habitat suitability for a larger part or all of a lake ecosystem. The first way is the primary one for site-specific applications, while the second is linked to larger-scale efforts to develop area habitat management plans for fish habitat. In both instances, it is necessary to delimit the areas of habitat affected or involved and to break down the areas into a series of discrete units or patches each with a distinct set of habitat characteristics. There is no *a priori* minimum patch area for these analyses and those using this approach must be guided by the resolution of the habitat mapping information available and the preciseness of the habitat classification criteria.

To compute the net gain or loss of habitat, one scenario must be designated PRE and another POST. Since the habitat area included in the PRE scenario is primarily defined by the modifications shown in the POST scenario, these scenarios will usually form pairs. In the planning phase several alternate schemes may be considered. Users will have to ensure that they have a way of documenting the differences among several PRE/POST pairs. Sometimes triplet scenarios will exist, consisting of the baseline pre-development case, the post-development case, and the post-development case with added compensation. The first scenario entered into the software package will be treated as the pre-development or baseline scenario for net change calculations. As application of this approach is intended to be a complementary precursor to authorization of development activity, the opportunity to obtain a map of pre development habitats always exists. The resolution and precision of the mapping required is not prescribed here but will be influenced by regulatory consideration of the potential extent of the impacts, the nature and significance of the fishery resource affected, the complexity of the situation, and the availability of prior mapping.

For a whole system supply analysis only one scenario will be used. The results can be used to refine fishery and fish community management plans, to identify restoration and conservation needs, to define upper bounds for human development, etc. A detailed example of a whole system analysis is described for Severn Sound on Georgian Bay (Minns et al 1999).

2.3.3 Area Designations

In Minns' (1995a, 1997) net change accounting equations for fish habitat, a number of different area types are defined. These area types are used to classify habitat patches in scenarios (Table 2.3.2) and provide a convenient basis for deriving an overview of a proposed development activity and associated loss, modification, and compensation areas.

By definition pre-development (PRE) scenarios cannot contain COMC areas and post-development (POST) scenarios cannot contain LOSS areas. MODD and MODI areas must be included in both PRE and POST scenarios, using the development dimensions to delimit them in the PRE. The MOD areas will have different habitat characteristics in the PRE and POST scenarios. When COMM areas are added to a POST scenario, those areas with their PRE habitat conditions are also added, though again the habitat characteristics will change. UNCH areas may be included to provide a complete habitat picture for the habitat patches involved but the area and habitat characteristics must be identical in both PRE and POST scenarios. UNCH patches make no difference to the PRE-POST net change calculations.

2.3.4 Habitat Characterization Options

The definitions for the habitat scenarios must include a designation of which type of depth, substrate, and cover assignment method will be used. There are two methods of assignment: A) the habitat features are specified as proportional vectors using a defined set of categories, normally those fixed ones present in the internal habitat requirements database, or B) habitat features are given arbitrary names or descriptors in the external scenario data file and the user links each name to a user-specified proportional vector. If an arbitrary set of categories is used in method A, the user will have to specify the a proportional vector elsewhere in the definition process. Where detailed analysis of habitat characteristics is available, method A might be appropriate. More often, habitat units are described in fairly general terms and only an approximate knowledge of the proportional composition is available, making method B more suitable. In general, method A is more appropriate where detailed habitat mapping has occurred and the units of habitat are relatively small. In coarser assessments, habitat units are relatively larger and method B is more appropriate.

The proportional vectors for the three habitat features have the following interval boundaries:

Depth – 0, 1,2,5, and 10 metres

Substrate – bedrock, boulder, cobble, rubble, gravel, sand, silt, clay, hard-pan clay, and pelagic

Cover - no cover, submerged vegetation, and emergent vegetation.

In method A, a substrate type containing 40 % cobble, 30 % rubble, and 30 % gravel will be represented as follows: 0,0,40,30,30,0,0,0,0,0 ensuring that the percentages sum to 100. In method B, the same substrate might be named CORUGR1 (for cobble-rubble-gravel mix 1) and in the habitat features the proportions would be entered manually.

There are a variety of ways the habitat characteristic information might be obtained. The simplest approach is to develop maps for each habitat feature and then overlay the maps to identify habitat units with distinct characteristics. For each habitat feature, the following guidance is offered:

Depth: Most information about depth will tend to be derived from existing contour maps and hence depths will most often be reported as a range. Although detailed habitat surveys may result in patches with specific depths assigned. Whether reported by range or specific value, the depth categories will have to be cross-linked to the depth ranges used to compute the habitat

suitability matrices. The simplest method of cross-mapping ranges is to use the depth intervals to compute proportions. For example, if an input depth range is 0-5 metres and must be mapped onto 0-1, 1-2, and 2-5 metre ranges, assume 20 percent is assigned to each of the first two ranges and 60 percent to the last, representing depth intervals of 1, 1, and 3 metres respectively.

Substrate: There are two basic methods of assigning substrate values to a habitat patch: categorical and exact proportions. In the categorical method, each patch is assigned one of a finite set of substrate categories based on various published schemes for designating substrate by particle size (Valere 1996) and corresponding to the categories used in the requirements database. For example, a patch may be designated bedrock, sand, or clay and for the purposes of calculating suitability, the patch is assumed to have 100 percent of that substrate type. Some categorical labelling systems correspond to fixed ranges of proportions method, e.g., Folk (1954). The centroids of each category in a Folk-like scheme can be determined and proportional composition determined. For example, patches may be described as sandy-gravel, silty-sand, or mud. Each label is consistent with a fixed range of proportions for gravel, sand, silt, and clay. When calculating habitat suitability, the substrate proportions are used to compute a weighted mean of substrate-specific suitabilities. In the exact proportions method, each patch has a vector associated with it specifying the proportions of each substrate category present. Again, the proportions are used to compute a weighted mean of suitabilities.

To ensure a correct matching of user-supplied substrate categories with those used for assigning suitability values, a proportional assignment matrix must be specified for the categorical and fixed proportion methods. Otherwise the input habitat scenarios must contain the proportions of substrates for all nine substrate types for every habitat patch. Anthropogenic substrates represent a challenge and will generate more debate. For example, if very large boulders are being used to construct a robust coastal feature, it is not equivalent to the boulder category in the internal requirements database. A more appropriate representation might be 65 % bedrock, 25 % boulder for the main characteristic plus 5 % rubble and 5 % sand to represent the patchy accumulations of finer substrates collecting in and around the interstices.

Cover: There are three ways of specifying cover in a habitat patch: (1) Categorical - no cover, emergent or submergent; (2) Proportional additive - exact proportions of area are provided and sum to 100 percent; (3) Proportional non-additive - proportions of emergent and submergent may overlap (some observers distinguish between vegetation in the water column and that which sticks through the water surface) (Table 2.3.3). In the categorical scheme, the user must have a defined basis for assigning one of three categories of cover and the weight is assumed to be 100 percent of that category assigned. In the proportional additive scheme, proportions are assigned to the three categories and sum to 100 percent. The proportions are used as weights for combining suitability values. In the proportional non-additive scheme, the no cover value is computed as $100 - \text{Max}(\text{percent emergent cover}, \text{percent submergent cover})$. The three proportions are then summed and used to re-weight the proportions so they add to 100 percent.

For the purposes of computing habitat suitabilities, habitat areas are orthogonally disaggregated into homogeneous sub-areas according to the percentage vectors of depth, substrate, and cover. For example, a habitat area of 100 m² assigned the following attributes: depth - 50% 0-1m, 50% 1-2m; substrate - 25% gravel, 50% sand, and 25% silt; and cover - 30% submergent and 70% no cover, would be disaggregated by the software as follows:

<u>Area, m²</u>	<u>Depth zone</u>	<u>Substrate</u>	<u>Cover</u>
3.75	0-1	Gravel	Submergent
7.50	0-1	Sand	Submergent
3.75	0-1	Silt	Submergent
8.75	0-1	Gravel	Nocover
17.50	0-1	Sand	Nocover
8.75	0-1	Silt	Nocover
3.75	1-2	Gravel	Submergent
7.50	1-2	Sand	Submergent
3.75	1-2	Silt	Submergent
8.75	1-2	Gravel	Nocover
17.50	1-2	Sand	Nocover
8.75	1-2	Silt	Nocover

These disaggregated data can be used to assemble habitat profiles using the reference classes, making comparisons of scenario information simpler. Corresponding HSM values are then used to compute the weighted suitable area (WSA) for each habitat patch.

2.4 Computation

2.4.1 Individual Species Habitat Suitability

The habitat requirements database for spawning, YOY, and adult life stages contain preferences for depth ranges, substrate categories, and cover. Preferences are rated as nil, low, medium, and high (0,1,2, or 3) for substrate and cover. Depth range preferences often vary seasonally with thermal patterns and life history progressions. Depth preferences were rated by the number of seasons involved (1,2, or 4) by Lane et al (1996a,b,c) but were represented as either nil or high when used in database used here. Each habitat feature is treated independently as there are few species for which non-orthogonal patterns have been described.

The initial suitability matrix (Figure 2.4.1) combining depth, substrate and cover categories is computed as follows (each matrix consist of a cube of cells representing all combinations of the three sets of categories):

- 1) Preference for a single category of a habitat feature, $P_{??}$ where ?? represents the habitat feature and category, has an integer value as described above. If preferences are initially expressed using a 0 to 1 numerical scale, the later computational outcomes are the same.
- 2) The preference for a combination of depth (P_{Zi}), substrate (P_{Sj}) and cover (P_{Ck}) categories is computed as the product of the constituent preferences, $P_{ZSCijk} = P_{Zi} \cdot P_{Sj} \cdot P_{Ck}$. For example, a species with a high preference (3) for sand, a medium preference (2) for submerged vegetation, in 0-1 metres of water in the spring (1) has a weight for that combination of 3 times 2 times 1 equals 6. Values for all cubes in the matrix can be assigned in the same way. If any one category has a zero, the matrix combination value is zero.
- 3) The combined preferences are summed over all permutations of depth, substrate, and cover categories to give:

$$P_{ZSC***} = \sum \sum \sum P_{Zi} \cdot P_{Sj} \cdot P_{Ck}.$$

- 4) Then proportional suitabilities are computed for each cell in the 3-way matrix of categories as the ratio of the cell preference to the preference sum:

$$S_{ZSCijk} = P_{ZSCijk} / P_{ZSC***}.$$

This ensures that the contribution of each matrix for a particular species-life stage to subsequent species and life stage grouping is equal to total weight of 1. S_{ZSCijk} represents the proportional suitability of a matrix cell.

2.4.2 Group Habitat Suitabilities

Having computed separate suitability matrices for all the species included in the Location list by life stage, those matrices are pooled by species and life stage grouping (Tables 2.4.1 and 2.4.2, respectively). [A combination of life stages, and trophic and thermal preferences have been the basic approach adopted for forming groups throughout the development of the HSM approach although other criteria for forming groups can be used. Whatever grouping criteria are users will have to provide a rationale for their choices.] Matrices are summed cell by cell and then the cell sums are standardized to a scale of 0 to 1 by dividing each by the maximum cell sum. Thus the group suitability is:

$$GS_{ZSCijk} = (\sum S_{ZSCijk}) / \text{Max}(\sum S_{ZSCijk}).$$

The life stage composite suitability matrices are generated by applying the fish species group weights and computing a weighted sum of the group suitability matrices. The overall composite suitability matrix is then computed from a weighted sum of the life stage matrices using the life stage weights.

2.4.3 Weighted Suitable Area (WSA)

Once the composite suitability matrices are prepared, the categorical characteristics of a habitat patch can be used to compute a patch suitability. If the habitat patch is described by a simple combination of the intrinsic habitat categories, e.g., depth - 1-2 metres, substrate - sand, and no cover, the appropriate suitability can be looked up in the matrix and assigned. If a habitat patch is described by a set of orthogonal vectors assigning proportions to depth, substrate, and cover category vectors, e.g., depth - 0-1 metres (0.5), 1-2 metres (0.5); substrate - gravel (0.25), sand (0.5), silt (0.25); and cover - nocover (0.5), submerged (0.5), the disaggregated homogeneous habitat sub-areas (see section 2.4.2 for details) are assigned suitabilities, and then pooled across the sub-areas.

When habitat suitability indices have been assigned to all habitat patches by fish group and life stage criteria, weighted suitable area (WSA) is calculated by multiplying the patch area by each of its corresponding suitability values. A single habitat patch may have a range of suitability values attached to it, representing different fish species or groups and life stages. Suitability for warmwater non-piscivores spawning may be high while suitability for coldwater adult piscivores may be low.

A fundamental assumption of this type of suitability methodology is the area equivalence of weighted suitable areas. For a given fish group- life stage criteria combination, 100 hectares with a suitability of 0.25 is assumed to be equivalent to 50 hectares with a suitability of 0.5.

2.4.5 Summation

After the WSA for each habitat patch has been computed, the sums by group and life stage criteria can be calculated for each scenario. The aggregate WSA values can be compiled for each fish group and life stage along with the composite, aggregate values generated via the weighted sums.

2.4.6 Cover Preferences

The mode of use of cover preference information was different than that for depth and substrate. With depth and substrate categories, all species and life stages have some preference recorded for at least one category of each habitat feature. Some species show no preference for submergent or emergent vegetation but there is no literature basis for inferring preference for no cover. A no cover category is needed to allow multi-factor suitabilities to be computed. To overcome this difficulty, an implied no cover category is computed based on the strength of other cover associations (Table 2.4.3).

2.5 Results

Users of the HSM method software are provided with a wide variety of options for examining the results of an assessment. The results may be viewed as windows interactively or printed in standard formats. As there are many layers to the calculations and many different ways of viewing the analysis, the approach with the software has been to provide access to all steps. Being able to examine results of intermediate steps in the calculations should help users understand and interpret the outcomes.

When printing the results of any analysis, the user can choose between a standard report or a custom selection of material drawn from the views generated in the interactive assessment. The standard report provides a minimum set of results that are used to judge net gain or loss of habitat productivity, documenting the various inputs provided and decisions made in setting up the analysis.

Additional result formats give the user the means of appreciating the detail underlying the more aggregated results. For example, the user may want to assess the contribution that centrarchid YOY requirements made to the WSA results obtained for non-piscivorous warmwater YOYs.

The user can assemble results based on habitat criteria, species (singly or in groups), or area type as well as the integrated assessment. The choices are made from a results options menu and then the results tables are generated for inspection.

The output may be grouped into a linked series of components: habitat criteria, species and group summaries, model specification, habitat supply and transformation, integrated assessment. Sample outputs have been generated using a pair of hypothetical scenarios for an exposed site on the Lake Ontario shoreline (Table 2.5.1).

2.5.1 Habitat Criteria

There are several types of information documenting the habitat criteria: a) habitat types and weights used, b) lake habitat classification, c) lake habitat classification for reporting, d) lake habitat input-output mapping for output, and e) lake habitat input-output mapping for input.

- Habitat types and weights: This is a listing of the life-stage habitat types considered in the analysis and the weights used when aggregating the weighted suitable areas (Table 2.5.2A).
- Lake habitat classification: This is a listing of the habitat features and classes present in the habitat preferences database for all the habitat types included in the assessment (Table 2.5.2B).
- Lake habitat classification for reporting: As above, this is a listing of the habitat features and categories considered in the analysis. These lists may be somewhat truncated compared to those in habitat types and weights and lake habitat classification if certain categories are considered unnecessary for a particular analysis.
- Lake habitat input-output mapping for output: The categories used to output results depend on the form of the categories used in the scenarios. If proportional vectors of categories were used, then those categories are used in the output. If vectors are not used in scenarios, the categories in the requirements database are used by default but can be reduced by combining them when the habitat types are specified in the definition phase. While two categories may be combined for output purposes, the suitability calculations for the analysis are performed for each category separately.
- Lake habitat input-output mapping for input: As the habitat feature categories used in the development of scenarios for analysis using HSM do not always correspond to those present in the habitat requirements database, it is necessary to map input categories onto database

categories. For instance, a substrate may be described as gravelly-cobble in a input scenario. This substrate can be mapped to the database categories by assigning proportions of gravel and cobble (Table 2.5.3). Those proportions have to be agreed among the experts and assessors acting for the proponent and the regulatory agencies. This step provides the user with some freedom with respect to the specification of habitat conditions in scenarios. If this user-specification approach is adopted, those responsible on the regulatory side for assessing analysis should make sure that the mappings are reasonable.

2.5.2 Species and Group Summaries

The species and group summary contains the group names, their weights, a count of the number of species considered overall and by habitat type, and the list of species associated with each group (Table 2.5.4).

2.5.3 Habitat Supply and Transformation

From the input scenarios, a series of habitat supply summaries are created (Table 2.5.5). By the area types listed earlier (Table 2.3.2) such as LOSS, MODD, etc., the equivalent areas are compiled for each category within each habitat feature. Each habitat feature is summarized independently, ignoring the combinations of categories present in any particular habitat patch. The categories used are drawn by default from the habitat preferences database if none are specified. However, they are better thought of as being provided by the user since they can be: a) changed from the defaults by renaming, adding to, or deleting, or b) fixed via the proportions directive when the scenario data is in the form of vectors of proportions. Area values are reported for all scenarios and for all habitat types, life stages are considered. Additional columns of results are generated, measuring the difference between the first scenario and other scenarios in that analysis. The net change columns provide a direct indication of where the greatest habitat changes will occur.

2.5.4 Integrated Assessment

The final table of results in the standard report gives an integrated assessment of the scenarios expressed as weighted suitable areas, areas times suitability values (Table 2.5.6). The WSA values are given by habitat type and fish group along with the combined and overall values. The overall sum of WSA represents the combination of all the constituents estimated obtained after the group and habitat type weights are applied.

Given that the many steps in the process necessary to define an analysis can be justified, the integrated assessment of WSA provides the simplest view of the outcome of different development options. The WSA values are assumed to represent a relative measure of natural fish productivity and a fair basis for comparison of pre- vs. post-development scenarios. The results of one analysis cannot be directly compared with the results of another unless the same assumptions are applied throughout. It is not practical to impose a fixed assessment regime for all users to produce uniform results for all applications. Each ecosystem, its fish assemblage, and fisheries has particular characteristics and hence flexibility in weights and criteria are necessary. The common element across all applications is that consistent rules are applied to the comparison of pre-/post-development scenarios.

Additional, more specific results tables can be generated at almost any stage in the reporting and selectively printed.

2.6 An Overview of Habitat Suitability Index Values

As an illustration, representative habitat suitability index values were computed using the complete Great Lakes basin fish habitat requirements database. All fish species were included and they were divided into eighteen groups based on thermal preference (warm, cool, or cold),

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trophic level (piscivore or not), and life stage (spawning, YOY, and adult). Then suitability values were computed using the HSM method for all unique combinations of habitat classes for depth, substrate, and vegetation. This process produced a matrix of eighteen suitability values for each of 150 habitat combinations. As the suitability indices generally show less variability within thermal groups, an arithmetic mean suitability was computed within each thermal group to provide a general guide to expected suitability values (Table 2.6.1).

The habitat suitability indices computed using the HSM model vary as expected from the source data in relation to depth, substrate, and vegetation cover (Figure 2.6.1). The charts were prepared by computing mean values across the three life stages, adult, yoy, and spawning to derive representative values. The charts for warmwater fishes show that higher suitabilities are centred on the gravel-sand portion of the substrate spectrum in shallower depth increasing from no cover through submergent cover to emergents (Figure 2.6.1A, B, and C). The charts for coolwater fishes show a similar pattern with higher preference for greater depths and lower peaks in submergent and emergent vegetation (Figure 2.6.1D, E, and F). The charts for coldwater fishes show a markedly different pattern (Figure 2.6.1G, H, and I). Coldwater fishes show little preference for submergent and emergent vegetation but the highest values occur again in shallow depth over gravel and sand reflecting seasonal spawning and fry habitat preferences. Overall coldwater fishes prefer no cover with a broad range of preference over substrates, narrowing to rubble, gravel and sand in shallow waters.

A simple correlation analysis among the 18 habitat suitability indices was performed using a tabulation of all unique combinations of depth, substrate, and vegetation categories to show the level of redundancy built into the approach especially among warmwater and coolwater groupings whose habitats are most often affected by nearshore development activities. The correlation matrix shows (Table 2.6.2) that all correlations among warmwater and coolwater indices are positive and significant at $P=0.01$, Bonferroni-corrected. There are few significant correlations between coldwater and either warmwater or coolwater ones. Among the coldwater indices, one third are positive and significant at $P=0.01$. The irregular pattern of correlation among coldwater indices is consistent with their more varied life-history patterns of habitat use. It should also be noted that coldwater species are more likely to have a life stage that is confined to streams and rivers, rather than lakes.

3.0 INFORMATION GATHERING AND DATA ASSEMBLY

3.1 Information Gathering

Unlike the situation with stream fish habitat where there are a number of recommended survey and assessment protocols for fish and their habitat (e.g. Stanfield *et al.* 1997), there are no universally established protocols for lacustrine environments in Canada. Several agencies and groups have prepared local guidelines and they should be used where available. There is a DFO research program under way with researchers in several DFO regions, as well as from Ontario Ministry of Natural Resources, engaged in studies to compare and test various survey methods in freshwater with a view to recommending guidelines. The guidelines will have to be flexible to allow the potentially enormous ranges and scales of site-specific conditions and development activities. It is not practical to dictate a single standard for lacustrine assessment from the vantage point of this tool as regulatory agencies have a range of factors and issues to consider when deciding what types and amounts of information to require for any particular development application.

Besides the actual details of survey design and execution, protocols should also address how the data collected can or should be used to aid decision-making. Too often assessment

protocols show how to collect and summarize data but not how to apply it to real-world contexts. The approach followed here is pragmatic and recognizes there may be several levels of protocols. The highest level of protocol may only be used in concentrated research studies or referral situations where unique, highly valued, highly sensitive fisheries resources are threatened by the nature and/or scope of the proposed development activities. An intermediate level might be used where a number of sites must be examined or where the extent of the area under review is very large. The lowest level might rely on a relatively quick, one-time inspection and description of the site with little actual sampling. The potential cost of applying different levels of protocol will always be weighed against the cost-benefit economics of the proposed development.

At this early stage in the evolution of complete survey and assessment guidelines for lake habitat, it is more appropriate to try to identify some benchmark characteristics for data gathering, allowing both proponent and regulator some leeway, then judging the adequacy of the data presented in support of a referral.

3.1.1 Position, Dimensions, and Context

This section refers to information normally expected by the regulator when reviewing an application and does not include any information specifically required for an HSM analysis.

- **Site Position:** It is essential that the exact location of the proposed development be known. By convention, an established hierarchy of government and land-ownership boundaries have been used to describe location. Now with the advent and widespread application of global positioning systems (GPS), it is important that exact geographical co-ordinates be obtained for a proposed development.
- **Project Dimensions:** The areal extent of the development activities as they affect fish habitat should be known. Other on land areas should also be reported, especially where the landward activities may indirectly impinge on adjacent fish habitat.
- **Lake Dimensions:** It is important to know something about the lake as a whole where a development is proposed. This information becomes more important for smaller lakes or if the project dimensions represent a larger portion of the lake. In larger lakes, it may be more appropriate to know the size of the bay or arm of the lake where the development will take place.
- **Context:** Knowing the above information for each referral becomes useful on an aggregate basis as the cumulative impacts of multiple developments on particular lake systems. (A referral is the process by which proponents submit descriptions of planned developments with details about the potential loss and modification of fish habitat to DFO and other regulatory agencies seeking a determination under section 35 of the Fisheries Act with regard to HADDs in fish habitat.) The overall levels of previous and anticipated development on a lake should be known in general. However it is difficult to make use of such knowledge in a particular referral unless there is an explicit habitat management plan for the whole lake with clear habitat conservation targets. Rareness and uniqueness of habitats important to elements of the fish community should factor into the overall decision-making process, even if they cannot be explicitly incorporated in the application of HSM methods.

3.1.2 Physical Habitat Characteristics

- **Depth:** Bathymetric data should be gathered with a resolution of at least one metre vertically as this is the finest level of resolution in the depth portion of the habitat requirements database. Variations in water level should be factored into the analysis where appropriate. The traditional high water mark may not be inundated very often. Hence, it usually makes

sense for proponent and regulator to agree on a reference datum, a norm, for the purposes of establishing which areas are fish habitat and which are not in an application. If an area is routinely inundated on a seasonal basis, it should be considered fish habitat especially as some life stages may make corresponding seasonal use of the habitat. If variation in water level is a significant issue, it may be appropriate to incorporate the variability by determining the percentage of time when each elevation is inundated and using that as a Condition Index in the evaluation of the fish habitat. However, a time budget can be misleading. For example, if an area is inundated for 20 percent of the year but routinely used for spawning and YOY rearing, the should be 100 not 20 percent. Attempts to derive a detailed, rigorous method for handling water level variation are likely to lead to onerous requirements that accomplish little in most instances.

- **Substrate:** In ideal circumstances, it would be preferable that substrate always be recorded on a uniform patch basis as a statement of percent composition using the particle size categories previously described. Such an approach could engender substantial survey and analytical costs. The resulting substrate data would likely have a level of precision far greater than that present in the fish habitat requirements database. This is not usually justifiable. Therefore, it is more reasonable that substrate areas should be delimited and estimated using visual descriptive methods. Obviously due attention should be given to ensuring that an adequate level of survey effort is directed to mapping substrate areas. A combination of visual survey and/or echo-sounding, and point grab samples for inspection with good positioning information, should allow a fairly accurate map to be generated. Often surveyors will record the presence of 'mud' or 'loon shit' as substrate types. These may be interpreted in HSM as being mixtures of silt and clay possibly with a minor contribution of sand. Man-made substrates such as rocky revetments and rip-rap are usually represented as mixtures of bedrock and boulders with small amounts of finer materials (cobble, rubble, gravel, etc.) depending on the amounts of interstitial space and surface pockets capable of accumulating and retaining them.
- **Cover:** The literature-based review of cover habitat requirements in lakes mainly produced information on use of submerged and emergent vegetation. However, in some instances, coarser substrates laying over finer ones, e.g. boulders and cobbles laying over a mixture of sand and gravel, can also provide some cover. With vegetated areas of habitat, the general approach is to take larger areas with particular depth and substrate characteristics and assign overall levels of vegetation cover, e.g., 20 percent submerged, 40 emergent and 40 with no cover, rather than generate numerous small areas with or without 100 percent cover. Given the method by which the habitat characteristics in percentage vectors are analyzed, the greater detail is unnecessary. In this version, information on other types of cover, such as larger detritus, woody debris, and overhanging vegetation, was rarely included. For non-vegetation types of cover, the approach has been to allow some leeway in interpreting them as having a percentage vegetation cover equivalence, weighed more heavily on submerged vegetation. Thus in a shallow shore area with 25 percent coarse woody debris cover, 15 percent submerged cover might be used in the HSM scenario. The lesser percentage takes some account of the lesser surface:volume ratios in woody debris and the space it occupies. Care must be taken not to abuse this stretching of cover definitions. [A new literature review is being undertaken to try to expand the range of cover types considered in the Great Lakes lacustrine habitat requirements database (Vokey-Cudmore and Minns, DFO Unpublished information).]

- Shoreline Exposure on the Great Lakes and other large inland lakes: As a result of cumulative experience with applications of the HSM method in the Great Lakes region, a situation has been recognized requiring a use of the Condition Index. On highly exposed shores, developers often propose to build breakwalls to accommodate marina and other recreational developments. In the lee of the breakwall, the wave exposure of habitats will be reduced. In the sheltered area indirectly affected by the breakwall, the depth, substrate and cover characteristics may be unaltered, especially as marina developers strive to balance shelter from waves with sufficient circulation to avoid the creation of stagnant areas. It is known from experience that fish abundance will increase in these sheltered areas although the composition of this fish assemblage may differ from that found in adjacent naturally sheltered, high productivity habitats (Randall and Minns 2000 in review). An analysis of an existing littoral zone fish-habitat database showed that a composite index of fish assemblage species richness, number and biomass per unit effort, and the Index of Biological Integrity (IBI) was higher on average in areas with a maximum effective fetch of 10 km than in areas with a greater fetch value, e.g. 1.0 versus 0.64 (see Appendix A for details of the derivation). This result provides a basis for using the Condition Index to reflect this outcome. In general the rule would be: If maximum effective fetch > 10 km set Condition Index (CI) = 0.64, otherwise CI = 1.0 (Table A3 provides a breakdown of Condition Index assignments). In practice this would mean that areas indirectly modified (MODI) in the lee of the breakwall or directly modified areas (MODD or COMM) on the leeward side of the breakwall would be assigned a CI value of 0.64 in the PRE-scenario and a value of 1.00 in the POST-scenario. LOSS areas in the PRE- scenarios would be given a value of 1.00 as they must be charged at the maximum productivity. MODD areas on the windward side of the breakwall will not experience any change in their exposure status and thus the 0.64 value would be used in PRE- and POST-scenarios. COMC areas are presumed to provide good quality habitat and are assigned a Condition Index value of 1.0 in POST-scenarios. ** It should be noted that this alteration is provided as an interim adjustment. The research necessary to distinguish between increased productivity in such habitats from a purely attractant-concentration effect has not been done. In the comparable situation of reefs, marine and freshwater, long-standing research has failed to distinguish between the two possibilities though a rising consensus suggests that the attraction effect may be greater, thereby indicating that no productivity increase can be inferred in such situations.**

3.1.3 Other Habitat Conditions

- Water Quality: Where the development will have no impact on prevailing levels of common water quality parameters such as nutrients, chlorophyll, temperature, conductivity, and turbidity, and where the overall state of water quality is judged to be satisfactory, no special consideration is needed. If activities associated with the development will lead to changes, positive or negative, in overall water quality, there may be a need to explicitly factor the changes into the HSM assessment. For example, if, as part of a shoreline project, stormwater flows would be managed to reduce sediment loads and hence local turbidity levels, it might be appropriate to make allowance for any deleterious levels at present and the improvement afterwards. This could be accomplished by setting the Condition Index to less than 1.0 in the pre-development scenario and to 1.0 in the post-development scenario. This type of productivity adjustments must be used with care and do not apply to LOSS areas. One situation to clearly avoid are unreasonable claims that water quality conditions are extremely poor now and will 'miraculously' improve after the development occurs. It is also worth

remembering that applying Condition Indices to modified and compensation areas in pre- and post-scenarios may increase the compensation area required to offset losses which are assigned maximum unit productivity values. Uses of the condition index will be closely scrutinized by regulators as there is potential for misuse and deliberate biasing of assessments.

- **Contaminants/Toxic Chemicals/Impaired Fish Health:** The presence of actionable levels of contaminants in fish flesh or fish food or of toxic chemicals in water or sediment, or the presence of higher levels of chemical-induced health impairments in fish and the biota they depend on, point to potential impairments of fish productivity and/or fishery products. The presence and potential impact of these factors can be incorporated into a HSM assessment. This can be achieved using the Condition Index. This should definitely be done when the proposed development will change the chemical situation. In situations where the proponent is not accountable for the chemically-induced phenomenon and the activities won't change them, their inclusion is probably unnecessary. In some Great Lakes' Areas of Concern, contaminant clean-ups and fish habitat improvement have been applied simultaneously to a site. In such instances, the proponent should be allowed the benefit of the improved usefulness of the fish habitat productivity in the HSM analysis.

3.1.4 Fish Community and Fisheries

- **Prior Research and Assessment:** Every effort should be made to assemble prior fish community data collected at or near the site as well as information about the lake or lake section as a whole. In some instances, there may be specific evidence of the uniqueness of the site as fish habitat that can be weighed into the decision process.
- **Fishery Exploitation and Management:** Evidence of the size and importance of local fisheries provide valuable supplementary information that can be used as a guide in the HSM definition phase. This information aids with the species list for the location and the formation and weighting of the fish groups.
- **New Fish Assessments:** Unless there are sufficient time and resources to conduct a thorough assessment of the fish community, on-site, locally, and possibly regionally, using standardized, benchmarked methods appropriate to the lacustrine habitats present, it is unlikely that new data derived from limited time, effort, and gear, can provide major new insights. Unlike in many regions in Canada and elsewhere where there are well-studied stream and river habitats, there are insufficient reference or benchmark fish community data gathered with standardized methods in lacustrine habitats to allow clear interpretation of new observations. Indeed, it is more likely that small amounts of incomplete data can confuse and obscure the main habitat management issues. The habitat policy is concerned with conservation, restoration, and creation of maximum potential habitat productivity for fish. Whether or not a few specimens of one or other species is caught at the site on one occasion is unlikely to reveal much about its productivity value. Clearly there are exceptions to these generalizations. If the sampling reveals a rare spawning location or the presence of a new or rare species, the evidence must be weighed into the assessment process, although it is unlikely to directly impact the HSM part of the assessment.

3.2 Data Assembly for an Application

There are several steps involved in the assembly of the input data before an application using HSM can be completed. The sequence of steps including analysis and assessment is outlined in a framework (Figure 3.2.1). The numbered steps cover the main sequence from a user perspective. The documentation should consist of numerical data, maps, and supporting text

rationales. Habitat characteristics and ranges should be developed with due attention to the classes used in the habitat requirements database. Development activities affecting habitat and compensation activities should be assessed in terms of their appropriateness, feasibility, and sustainability. It is vital that users thoroughly document their evidence and decision processes as they assemble their data files and definition criteria.

3.2.1 Physical Habitat Assessment Scenarios

- **Development Activity Footprint:** The first step is to define the total development footprint as it affects fish habitat. This footprint area is divided into the three area types: LOSS, MODD, and MODI. The first two should represent the direct construction effects while the third may arise as a result of new structures altering current, flow, sediment transport, and other conditions in adjacent areas (Figure 3.2.2). Determining MODI might involve some modelling or simulation (item 1b in Figure 3.2.1).
- **Existing Habitat:** Once the affected habitat areas have been identified, the existing habitat characteristics including depth contours, substrate and cover types should be mapped. Next delimit separate patches of existing habitat with relatively uniform characteristics. Note should also be made of other factors such as water uses and water quality impinging on the habitat, and of adjacent terrestrial habitat conditions.
- **Intersect Footprint and Habitat Areas:** Using the footprint and existing habitat maps, intersect the areas to define a set of areas with defined area type and habitat characteristics. This provides the basis for the pre-development scenario.
- **Post-development Habitat:** In the modified areas, estimate what the habitat characteristics will be after the development has taken place and stabilized. This may require some further sub-division of areas to capture various transitions of depth, substrate, etc. This process should be well documented.
- **Pre- and Post-development Scenarios:** Now both scenario files can be prepared. Ideally, non-LOSS areas should be uniquely identifiable in both PRE- and POST-scenarios files to make comparisons of on-site habitat changes easier to track and assess. LOSS areas only appear in PRE-scenarios.
- **Compensation Options:** Compensation areas should be defined separately, but may either be included in the initial pair of scenarios or introduced into a second pair of scenarios to help highlight the benefits of the compensation measures.

3.2.2 Cross-link Scenario and Database Habitat Classes

When setting up an application of HSM, there are two options for specifying the linkage between the habitat classes used to define the scenarios and the habitat classes used in the habitat requirements database used by HSM to estimate suitabilities.

In the first option, depth, substrate, and cover characteristics of habitat areas are given an account using vectors describing the percentage composition of all the classes within each characteristic. For example, a substrate characteristic for one area may be described as 25 percent gravel, 50 percent sand, 15 percent silt and 10 percent clay. As all substrate classes (bedrock, boulder, rubble, cobble, gravel, sand, silt, clay, hardpan clay, and pelagic) may be reported, the substrate vector will be entered as "0,0,0,0,25,50,15,10,0,0". If this approach is taken, the scenario and area reporting classes are automatically linked in the analysis phase.

In the second option, the user may create their own labels for habitat classes, e.g. shallow, deep, gravelly-sand, bedrock-boulder, armour1, armour2, veggy, sub25emer10, etc. Then during the creation of the application definition, the user may have to provide the input necessary to link scenario and area reporting classes. Since different life stages of fish have slightly different set of

habitat classes, this linkage information is required for all life stages and habitat characteristics. For instance, gravelly-sand may be mapped into the database as 25 percent gravel and 75 percent sand, or armour1 as 50 percent bedrock, 30 percent boulder and 20 percent rubble, or shallow as 60 percent 0 to 1 metres and 40 percent 1 to 2 metres.

In either option, it is important that both the users, project proponents and regulatory assessors, pay attention to the choices made to characterize habitats as the choice can greatly influence the suitability values assigned to different habitat areas. Before attempting to use the software to create a definition and run an analysis, the user should prepare the class mapping information and gather relevant supporting evidence and rationale.

3.2.3 Fish Community, Ecosystem Type, and Fishery Objectives

Documentation and evidence of the fish community, ecosystem characteristics, and fishery objectives for the lake, or region of the lake should be gathered as a backdrop to the specification of species to be considered and the various weights required. This step will often involve consultation with other agencies and individuals, as well as local and regional planning documents.

The fish community list should be complete. In the case of smaller inland lakes, tertiary watershed scale list are preferable to incomplete lists for specific locations. In the case of large lakes, the entire species list should suffice. Longer, diverse lists will tend to produce more stable, robust suitability values while short lists could produce misleading results. Given the potential for species turnover, the assessment should be weighed toward the long-term mean potential of any lake to support fish. Besides, the Fisheries Act mandate embraces all fish as potential contributors to fisheries productivity.

A consideration of the lake ecosystem characteristics should have some bearing on the refinement of the species list. For example if a lake is too shallow to support a hypolimnion during the summer, there is little point including lake trout or related species in the analysis. Equally, if the lake is in an area not included in the distribution of a species, that species should be excluded. As more evidence emerges on the general patterns evident in the occurrence of fish species in lakes, it should be possible to provide refined guidance of the assembly of a fish species list. [Work is underway to create a reference library of fish species occurrences by tertiary watershed for all of Canada as well as for larger waterbodies.]

The fishery management objectives, as defined by the appropriate management agency, should be taken as a starting point for identifying preferences and weights among the fish community. Considerations regarding rarer species, trophic structure, and the potential productivity contribution of various species should be considered. Often fishery management plans are directed at exploitation with secondary consideration of community structure and sustainability in the longer-term. Generally the fish community objectives for the site should preferentially take a longer-term, ecosystem view rather than a narrowly defined fish exploitation view.

3.2.4 Location Spp., Fish Group and Life Stage Weights

To complete the definition phase of the HSM application, the user must select a species list, assemble the species into groups, and assign weights for fish groups and life stages. The location species list is based on information gathered in the previous step.

Fish groups can be assembled using thermal preferences (warm, cool, cold) and trophic position (piscivore vs. non-piscivore). This divides the potential species list into six groups. This set of groupings is recommended as a default choice. Other criteria might be used to group the

fish species but clearly ecological criteria are preferable to others that might be based on potential use of the fish or their origin.

The fish group weights are set to be equal as the default option. The weights can be reset to recognize the fishery and/or ecosystem attributes shaping fish productivity in the lake. In large lakes, the weights may be directed to local priorities rather than global ones. For instance, in Lake Ontario, the offshore, coldwater pelagic fishery is the main one but inshore, given past habitat losses and alterations and a desire to restore stream-nearshore-open lake linkages for fish communities, weights showing preference for warmwater and coolwater species may be more appropriate.

In selecting the fish group weights, it should be recognized that small weight differences will not make much difference to the final analysis results. Analyses of the effect of various increments was reported in Minns et al 1999 (SEVERN SOUND RPT). Generally increments of 10 percent or more are needed to induce significant outcome changes. Since non-piscivorous species outnumber piscivorous ones, the fish group weighting process allows the opportunity to place greater emphasis on piscivores which obviously play a greater role in exploitation of fishery resources.

The life stage weights are set independently of the fish group weights and apply equally to all fish groups on the assumption that all life stages are important to all species if viable stocks are to be sustained. The default option assumes that all three life stages are equally important. There are various opinions and limited definitive evidence to guide the choice of weights here. It is worth noting though that HSM results are less sensitive to differences among life stage weights than they are to thermal preference and trophic level weights for fish groups (Minns et al 1999).

3.2.5 Assessment and Analysis Steps

Once all the data for scenarios and species lists have been assembled and weights assigned, the analysis can proceed. The first results inspected are the overall ones showing weighted suitable areas for each scenario with a breakdown by fish group and life stage. The estimates obtained here will largely determine the next steps in the referral process. There are always winners and losers when WSA is examined across the fish groups. Multiple scenario pairs can be examined simultaneously as alternate options are evaluated and preferred options refined. The second results inspected are usually the area summaries where the overall changes in habitat are summarized. Many constituent results tables are available for inspection where the user seeks clarification of the overall results.

Once the iterative analysis of scenario pairs is complete and a preferred option identified, the detailed report of the analysis and all key assumptions can be printed and added to the other referral documentation, detailing the proposed development activities, current and expected habitat conditions, and mitigation and compensation measures.

4.0 CASE STUDIES

Both case studies provided here originate from Halton Region on Lake Ontario. They are described with more contextual detail in Minns and Nairn (1999). Greater emphasis has been placed on the implementation of the HSM computations in this presentation of the case studies. The first case study comes from Burlington where the municipality is engaged in a long-term program to develop its shoreline areas as a recreational resource for local citizens and tourists. The second case study involves a private property owner in Oakville whose shore protection structures were in urgent need of replacement or restoration. HSM was applied in both cases with the assistance of staff in the Fish Habitat Management (FHM), Ontario, group with Fisheries and

Oceans. In both cases, the interaction enjoyed the support and cooperation of the consultants working for the proponents, local municipal planning offices, and the Halton Regional Conservation Authority who have responsibility for managing the coastal zone.

4.1 Case 1: Brant Inn Node, Burlington, Ontario

4.1.1 Background

The Brant Inn Node waterfront occupies about 300 m of frontage east to west from a formal park in downtown Burlington to the Burlington Beach park. Historically, this shoreline featured a transition from the sandy bay mouth barrier beach to the eroding shale bluffs to the east. Over the last century this shoreline was significantly altered, initially when the opening to Burlington Bay was shifted from near the site to the present location, a canal further to the south, and then by ongoing lake-filling to support a rail line, and later to protect the land base of the old Brant Inn. Prior to this project, the frontage was protected by concrete sea-walls, armour stone, and concrete rubble in varying states of disrepair, illustrated in Figure 4.1.1A. The near shore area at the site consisted of two separate zones with exposed shale bedrock in the small embayment and further to the east, sandy substrate from the old Brant Inn Pier towards the south and Burlington Beach. Due to its position in the north-west corner of the lake, the only wave exposure is towards the east.

The City of Burlington, and its partners (the Halton Region Conservation Authority and the Region of Halton), plan to develop the Brant Inn Node to create a highly animated point of interest at the meeting place of two distinctly different park environments. The aim was that the new development would meet a range of recreational and aesthetic objectives. W.F. Baird & Associates were retained to develop a series of concepts to regenerate the shoreline and waterfront area, to undertake a process to select a preferred alternative and to complete final design for this option.

Seven potential options were developed that ranged from a minimal footprint approach where the existing shoreline position was maintained to options involving significant amounts of lake-filling. Based on the vision statement and a series of objectives outlined by City staff, a group of evaluation criteria were prepared to assess the various options in order to select a preferred option. Through the public consultation process and through input from City staff, the evaluation criteria were ranked in order of importance as listed below (from most to least important): 1 - Public access; 2 - Visual impact, 3 - Water quality, 4 - Aquatic habitat, 5 - Open space, 6 - Terrestrial habitat, 7 - Year-round use, 8 - Impact on surrounding land use, 9 - Heritage resources, 10 - Costs, 11 - Day use boating, 12 - Potential for construction phasing, and 13 - Recreational fishing.

4.1.2 Process

The City of Burlington along with its partners approached Fisheries and Oceans FHM to obtain guidance on how to proceed from the initial set of seven options, including the option of doing nothing (option 0 on Figure 4.1.2A). FHM suggested that the proponents use the HSM approach both to screen the initial redevelopment options and then, once the option set had been narrowed, to refine and detail a preferred option showing a net gain of productivity of fish habitat whilst meeting the City's objectives.

Based on consultations with Ontario Ministry of Natural Resources and DFO staff, the fish community objectives for the HSM assessment were weighed equally among the three thermal and two piscivore/non-piscivore groupings of the Lake Ontario fish community. The main lake fishery is dominated by stocked coldwater species. Historical development along the Ontario shoreline in the western portion of the lake removed a lot of littoral habitat features that

supported warmwater and coolwater species and helped link riverine and open lake habitats. The overall goal is to restore a more balanced mix of habitat use and productivity in the littoral regions of the lake. As experts were sure that coldwater habitat features were abundant in the lake, the proponents were encouraged to include habitat features enhancing productivity for warmwater and coolwater species. Wetland habitat creation was also encouraged, albeit on a small scale, as historical coastal wetland losses on Lake Ontario have been very extensive.

4.1.3 Application

A consultant team, consisting of coastal engineers (W.F. Baird & Associates), environmental scientists (Gartner Lee) and landscape architects (Fundamental Design) proceeded to rate each of the six options against the City's thirteen evaluation criteria. Meanwhile, an application of the HSM approach proceeded to determine the impact in terms of the net change in Weighted Suitable Area (WSA) between pre- and post-development scenarios. Only two of the seven options came close to achieving a net gain and minimizing the area affected (Figure 4.1.2B). Several refinements of the options showing a net gain were evaluated until a final option meeting Fisheries and Oceans' requirements and the City's objectives was obtained. The preferred option, which was ranked highest regarding aquatic habitat (highest WSA gain), features the following components: a) A wetland (0.10 hectares in area) excavated from the existing land base, connected to the lake, and protected by a revetment and a shoal in the entrance; b) The reconstruction of the Old Brant Inn Pier to create an area for public gatherings and day use boat mooring; c) Lake-filling of the small embayment (0.27 hectares in area) to create more land base next to the main access point for pedestrians and vehicles; and d) A cobble beach between two rubble-mound headlands (Figure 4.1.1B).

The HSM assessment of the preferred option consisted of defining areas lost and areas directly modified and was used to refine the design to maximize the WSA gain. To define the scenarios pairs (pre- and post-) for each option, the areas bound by defined homogeneous features with respect to depth ranges, substrate types, and cover characteristics were estimated from design plans. Areas were also sorted to their pre- versus post-status according to the scheme described in Table 2.3.2. The areas were defined by W.F. Baird & Associates for the design team and the HSM model was run by DFO staff. In simple terms, the lake-fill area was a loss, consisting of exposed bedrock (with low habitat quality), but was more than balanced by creating a smaller area of higher quality wetland habitat in addition to improved habitat associated with the cobble beach and the rubble-mound structures. Using the new algorithms relating the survivorship of macrophytes to threshold wave conditions (W.F. Baird & Associates 1996), the width of the opening to the wetland was maximized and the crest elevation of the revetment was minimized.

4.1.4 Results

Meeting the park and recreational objectives of the City of Burlington required loss of a large area of habitat, 2690 m², and modification of a further 2203 m² (Appendix B). As the shoreline is subject to substantial wave energy, a large area had to be armoured. The pre-scenario shore was dominated by bedrock with scattered areas overlain with sand. The modification of a large section of shoreline to generate a cobble beach and creation onshore of a small wetland (1000 m²) with both emergent and submergent vegetation provide the basis for offsetting the direct losses.

In the suitability and weighted suitable area (WSA) calculations equal weights were used for six groups of fish based on thermal preference and piscivore/non-piscivore combinations for the three life stages. The overall WSA results indicated a shift from 598.2 to 744.4 equivalent

area units (actual areas are scaled by dimensionless suitability values with a range 0-1; an equivalent area unit is the area the WSA would represent if the suitability were 1), an increase of 146.2 units or 24.4 percent (Table 4.1.2). The WSA changes were not evenly distributed among the life stages. The YOY WSA shows a loss of 76.0 units or 12.5 percent and was due mainly to the reduction of habitat with sand substrate. The adult and spawning WSA showed large gains. Among the fish groups, the coolwater non-piscivores and both coldwater groups show losses of both adult and YOY WSA (Table 4.1.2), ranging from 19.8 to 728.2 units. Coldwater piscivore habitat shows the greatest percentage losses. Warmwater groups and coolwater piscivores show WSA gains for all three life stages.

The Brant Inn Node results demonstrated the benefits to be gained via the creation of habitats like a wetland, which have very high suitability values. Many species make use of emergent and submergent vegetation during one or more life stages (Lane *et al.* 1996 a,b,c). The loss of large sandy habitats and their replacement in modified areas with cobble and armour-stone would by itself have produced net losses as more species make use of fine-textured substrates than coarse ones. The overall net gain was achievable only with the creation of a small wetland by excavation onshore.

4.1.5 Outcome

The final design of the preferred concept was submitted for review under the Canadian Environmental Assessment Act (CEAA) at the beginning of August 1997. CEAA requirements have no direct link with fish habitat management. Only fish habitat managers, e.g. DFO, are concerned with fish habitat but the decision to authorize a HADD triggers CEAA under federal legislation. With the benefit of having already completed a HSM assessment indicating a gain in WSA, an Authorization was provided under Fisheries Act later in October of 1997 and approvals were also received in October from Coast Guard, Halton Region Conservation Authority and the Ontario Ministry of Natural Resources. Construction on the project commenced in November 1997.

4.1.6 Commentary

This case study illustrated the three stages in the progress from assessment to authorization when the HSM analysis played a role. First, it helped narrow the range of initial options by constraining the set to those showing a net gain or a potential, through modification, to attain a net gain of habitat productivity. Second, it helped with the iterative process of refining the preferred option as the planners and their consultants sought to maximize the attainment of their park development objectives while retaining the ability to meet the no net loss goal when requesting an authorization. Third, the completion of analysis and documentation of the final, preferred option meant that Fisheries and Oceans regulatory staff had a very good appreciation of the fish habitat implications of the proposed development activity when issuing the authorization.

4.2 Case 2: Wallik Property, Oakville, Ontario

4.2.1 Background

The owner of a property in Oakville with 29 m of frontage on Lake Ontario required restoration of the shoreline protection. The shoreline consisted mostly of an eroding shale bluff 6 m in height. The Shoreline Policy of the Province of Ontario requires that erosion hazards be addressed through shoreline stabilization (where necessary) prior to the municipal approval of site plans under the Planning Act.

Historically, this shoreline would have consisted of an eroding shale bluff with shingle beaches at the toe of the bluffs supplied by the natural process of bluff and lake bed erosion.

During this century, more than 75% of the Halton shoreline of Lake Ontario was protected with some form of sea-wall or revetment (personal communication, Teresa Labuda, Halton Region Conservation Authority). Therefore, much of the natural source of shingle supply was eliminated and any beach or near shore deposits of shingle were largely eliminated (resulting in narrow or non-existent beaches and a lake bed swept clean of loose shingle deposits).

Prior to the development of design alternatives, the owner of the property indicated his objectives for shoreline treatment: a) Improve access to the water's edge from the top of the bluff; b) Encourage beach development for access to the water's edge; c) Provide cost effective long term shoreline stabilization; d) Protect the crest of the bluff with bioengineering techniques, where possible, rather than with a large coastal structure; e) Minimize the crest elevation and visual impact of the shoreline protection; f) To the extent possible, naturalize the shoreline; and g) Minimize the potential for future maintenance of the shoreline treatment.

The coastal engineers, W.F. Baird & Associates, developed five conceptual designs for their client: (1) Do nothing and monitor the future erosion; (2) Construct offshore breakwaters and place imported beach material; (3) Construct a rubble-mound headland and allow beach to develop from natural supply; (4) Construct a rubble-mound scour pad at the toe of the bluff; and (5) Construct an armour-stone wall. A qualitative assessment of the options was made based on the application of the client's objectives and the nine principles for an ecosystem approach to shoreline treatment promoted by the Waterfront Regeneration Trust (see WRT 1996): clean, green, usable, diverse, open, accessible, connected, affordable and attractive. The construction of offshore breakwaters and the placement of imported beach material was considered the only option meeting all of the client's objectives and most of the nine principles.

4.2.2 Process

Initially, the innovative, ecosystem approach to shoreline treatment selected by the client encountered significant resistance from the approving agencies. There were concerns about the impact to fish habitat under the Fisheries Act administered by the Ontario Ministry of Natural Resources (OMNR) and the federal Department of Fisheries and Oceans (DFO), issues about infringement on the lake bed under the Public Lands administered by OMNR and concerns regarding navigation under the Navigable Waters Protection Act administered by the Coast Guard. Recognizing the importance of the precedent in promoting an innovative approach to shoreline treatment for this heavily developed section of shoreline, the Halton Region Conservation Authority (HRCA) brokered a meeting on 5 June 1997 between representatives of all the concerned agencies, the client and his designers. The catalyst for a consensus to approve the innovative shore treatment approach in an expedient manner was the application of the HSM approach to assessing fish habitat.

4.2.3 Application

The basis for the application of the HSM approach was the comparison of the pre- and post-conditions illustrated in Figures 4.2.1A and 4.2.1B. The preferred alternative would alter several physical characteristics of the existing habitat conditions along the Wallik shoreline. The offshore breakwaters would be constructed directly on the exposed shale lake bed. This would result in some lost lake bed area as well as modification of exposed shale to armour stone with interstitial spaces. Around the breakwaters, 8 to 20 cm cobbles would be placed over the existing exposed lake bed. Therefore, the impacts consisted of areas lost and directly modified areas, for this small project the indirect impacts were assumed to be insignificant. W.F. Baird & Associates defined the pre- and post-project physical conditions by areas with defined habitat

characteristics and DFO staff applied the HSM software to define WSA for the pre- and post-development scenarios.

4.2.4 Results

To meet the shore protection objectives of both the property owner and Halton Region Conservation Authority in a highly exposed location, there was no scope for creating sheltered fine texture substrates with cover. The area losses were kept to a minimum (77 m²) and the main modifications produced cobble beach overtop the bedrock retained with appropriately placed boulders (250 m²) (Appendix B).

Replacing bedrock with cobble and some boulder substrates generated the increased WSA, rising from 7.6 to 37.4, an increase of 392.1 percent (Table 4.2.1). Among the life stages, the largest WSA gain was for spawning while the largest percentage gain was for adult. In the pre-development scenario, the WSA was zero for 9 fish group by life stage combinations. The greatest WSA gains were obtained for spawning coldwater non-piscivores (77.5 units) and adult coolwater non-piscivores (77.3 units). The only losses were spawning warmwater piscivores (-6.4 units) and YOY coolwater non-piscivores (-0.1 units).

These results for the Oakville site are easily interpretable. Bedrock is a substrate favoured by few species (Lane *et al.* 1996 a,b,c). As a results, relatively low suitabilities would be applied to bedrock and replacement with other substrates, even relatively coarse ones such as boulder and cobble would result in net gains.

4.2.5 Outcome

The preferred alternative received an Authorization for Works or Undertakings Affecting Fish Habitat from DFO and an authorization to proceed by Coast Guard both on 6 October 1997. HRCA provided authorization to proceed also on behalf of OMNR and the Public Lands Act in a letter dated 24 October 1996. Construction commenced in November 1997.

4.2.6 Commentary

Prior to the intervention of the HSM application, the parties had tried to reach a consensus without success. The results of the analysis of the preferred option provided all parties with a fuller basis for discussion and shared understanding.

5.0 DISCUSSION

5.1 Conceptual Foundations

There are four main foundation elements in the Habitat Suitability Matrix (HSM) approach: a) the use of comparative assessments of habitat preferences by species and life stages to derive numerical habitat suitability index models, b) the balanced assessment of habitat productivity losses and gains to meet the Policy's guiding principle of 'no net loss', c) the use of weights to integrate the differing requirements of various elements of the fish community, and d) the use of a more pragmatic perspective to the application of this numerical assessment tool in the workaday environment of fish habitat management as compared to the more rigorous work of scientific research.

5.1.1 Habitat Suitability Index Models

The habitat suitability indices used here as surrogates for fish habitat productivity are based on simple measures of preference and predicated on the key assumption that use of habitat is an indication of that habitat's contribution to fish productivity. The use of simple preference measures is dictated by the lack of detailed quantitative assessments of the importance of various habitat for most species and life stages. It is argued that the accumulation of this preference data across numbers of species and life stages leads to more reliable, aggregate indicators of habitat productivity. This approach is consistent with the general tendency present in much of

conservation biology to infer that sites supporting greater numbers and diversities of various taxa have greater significance to the persistence of that biodiversity than sites supporting lesser amounts.

The simple species-life stage suitability models used here can be viewed as an intermediate point on the gradient between no knowledge and understanding of habitat requirements and complete knowledge and understanding; the former being a closer representation of the current situation for many species and the later being an ideal, unattainable situation. In the minimum model where it is assumed that nothing is known about habitat requirements, the null hypothesis that all habitat classes are equally preferred, and hence have equal suitability, applies under the rule of the Precautionary Principle. In this case, application of HSM leads logically to the outcome that all losses have to be matched by the creation of new compensatory habitats since all suitabilities are the same and no differential productivity changes are possible. Increments in the amount known of the differences in habitat preferences leads to differences in habitat suitabilities and hence increases the flexibility in attaining no net loss.

Much of the basic framework for the development of habitat suitability index models and their application was laid down during the establishment of the Habitat Evaluation Procedures (HEP) in the late 1970s and early 1980s (USFWS 1981). Terrell *et al.* (1982) described the specific information needs for lacustrine and riverine HSI modelling for HEP. Most HSI models were developed as consensus models assembled according to groups of species via workshops of ecosystem experts aided by facilitators and modellers. In HSM, systematic literature review has been used to replace the consensus workshop modelling. In aquatic applications of HEP, especially lacustrine ones, whole systems were the unit of assessment and hence many suitability models were assembled using whole lake characteristics such as area, mean depth, and water quality measures, as predictors for fish performance. In HSM, the assessments are focused on sub-areas in lakes and hence the fact that most of the HSI models could not be transposed or reused though the general lake level information is highly relevant to establishing the overall context.

5.1.2 Balancing Losses and Gains

The approach to fish habitat management embodied in both the Fisheries Act and the Policy represents a Kantian rather than a utilitarian (Sagoff 1996) framework for environmental management. The Fisheries Act takes a rule-based approach based on non-monetary considerations of the necessity of fish habitat and its productivity for fish to persist and thrive, and hence sustainably support fisheries. The methodology assembled in the HSM method is based on that approach and framework. Only fish habitat is considered in the analyses.

In many respects, HSM represents a constrained non-monetary form of cost-benefit analysis (CBA). CBA in a general context clearly represents a utilitarian approach wherein all elements are assigned a monetary value. The replacement of goods and services with money renders all things interchangeable. This utilitarian approach is not the course followed in the Fisheries Act and the Policy. HSM uses weighted suitable areas as a surrogate currency for fish habitat productivity and within the confines of the analysis the monetary costs of alternate habitat scenarios are not considered. Indeed there is no mandate within the Fisheries Act provisions or the Policy for considering monetary issues. However, the HSM does reflect many of the principles identified by Griffin (1998) as being fundamental to CBA. Where a principle is not matched, the future potential for making it match is identified. Griffin laid out eight principles and for most of them a non-monetary equivalent is presented in HSM (Table 5.1.1) and expanded upon as follows:

- Benefits exceed costs – a non-negative outcome from the weighted suitable area analysis is necessary before a proposal is deemed acceptable according to HSM.
- Differences – the approach requires a balanced comparison of PRE- and POST-scenarios with the welfare of the fish being the only consideration.
- Measurement units – unlike in CBA where costs and benefits are valued with mixes of production and consumption costs, fish habitat productivity values are used consistently throughout.
- Producer and consumer net benefits – the net productivity changes treat fish as producer and consumer with human intervention as an externality. Unlike CBA, supply and demand factors with respect to fish habitat productivity are not currently considered in HSM. However, the need to develop ways of considering such factors as reflected in density dependence mechanisms is recognized here and in Minns *et al.* (1996). The current approach is consistent with conservative, precautionary methodology.
- Zero-sum transfers – If loss of one area of fish habitat appears to be exactly matched by creation close by of an equivalent area, both areas are considered in any analysis as no change in habitat induced by a project and can be ignored. However, inclusion of habitat areas unaffected by the project is not recommended as the productivity values associated with them may distort the interpretation of the analysis.
- Temporal discounting – Temporal discounting of habitat productivity changes is not used in the current version of HSM. Pre- and post-development scenarios are assessed as if they will persist forever. There are circumstances when discounting might be required such as when temporary changes in habitat productivity occur over and above those described in the pre- and post-scenarios. For example, a mine might be developed, operate for 20 years, and then be decommissioned. The PRE-scenario would be based on the pre-development condition and the POST condition after decommission. In the intervening period, some habitat productivity may be unavailable due to temporary uses of the fish habitat. To bring the between-scenario into the overall analysis would require some form of discounting. At present, no basis for deriving discount rates for temporary losses of habitat productivity has been identified.
- Unmeasured changes – Issues such as the cultural concerns of area residents such as First Nations, the existing or potential fisheries activities, or the presence of threatened species or populations are not explicitly factors in a HSM analysis but are taken up in the decision process followed by those managing fish habitat under the Fisheries Act.

5.1.3 Use of Weights in Decision-making

The use of weights in HSM recognizes that there are many sets of habitat requirements and fishery objectives that must be factored into the analysis of net change of fish habitat productivity. The weights are necessary to resolve potential conflicts among elements of the fish community as habitat alteration inevitably involves a balancing among specific winners and losers. The basic method for deriving weights here is based on a consensus using ecological and fishery criteria. If the proponents and regulators have difficulty reaching that consensus, the more structured methods could be employed to bridge any impasse. The basic approach adopted here for HSM reflects methods that are well-established in other decision-making contexts where numerical methods are used.

Healey (1984) provided one of the early examples of multi-objective, multi-player decision-making in a fisheries context. He applied weights to sets of criteria for two fisheries, Skeena River salmon and New England herring, where the overall objective was to define an

'optimum yield'. Several interests were represented in each case study and there was a desire to balance conservation, economic, and social objectives. Healey's approach was based on the principles laid out by Keeney and Raiffa (1977) in their book on decision-making, a keystone reference for most subsequent decision-making research. Minns *et al.* (1993a,b) applied Saaty's (1982) analytical hierarchy ranking technique for deriving weights in decision-making in an application of Kozlowski's (1986) threshold approach to fish habitat assessment in Hamilton Harbour. Maguire (1986) gives another biological example concerning the management of endangered species. Munda *et al.* (1994) and Snell (1994) provide overviews of the range of environmental decision-making aids where multiple objectives must be reconciled.

5.1.4 Pragmatism versus Scientific Rigour

Wilk (1985) in a discussion of the role of science in decision-making regarding control of acidic precipitation in North America quoted Kant's advice: "It is often necessary to make a decision on the basis of knowledge sufficient for action, but insufficient to satisfy the intellect." Whenever there is an attempt to build links between science and management, issues arise about which codes of practice and traditions should prevail. Viewed as a product of science, it might be argued that the usual rules should apply, e.g., testable hypotheses, experimentation, replication, statistical significance. These are stringent requirements and cannot be applied on a day to day basis when applied in a practical management context. A healthy dose of pragmatism is necessary if tools grounded in science are to be developed and brought into routine use.

HSM represents a short step, comparable to Rigler's (1982) characterization of the current state of empirical ecology, on the road from "we can predict nothing" to "we can predict everything." While the tools and methodologies must be well-grounded in the available science, their application must be viewed as a small step from a position where decisions are made in a context of almost complete ignorance without the benefit of any systematic, quantitative assessment toward an unachievable position where decisions are made in a context of complete knowledge with the benefit of a statistically verifiable quantitative assessment. HSM is an empirical approach with no pretensions of providing an explanatory model of how fish productivity derives from the productivity potential of habitats. It is designed for its intended use as a problem-solving tool from the outset.

Funtowicz and Ravetz (1994) recognized three types of problem-solving science: applied, professional consultancy, and post-normal, dependent on the interplay of the level of uncertainty and the perception of the decisions stakes. Applied science operates where the uncertainties and the stakes are low and represents the normal view of science where well-defined puzzles are unravelled without critical external decision pressures. Post-normal science is presented as the arena where the really big issues like global climate change and sustainability are tackled with big human stakes and immense complexity and uncertainty. HSM is designed for use in the intermediate science realm of professional consultancy. There the problem-solving involves direct client service with unique situations involved. For the participants, the stakes are comparatively high but not of global concern. The situations may be similar to others but it is the particular set of circumstances in time and place that must be resolved. Funtowicz and Ravetz (1994) proposed that professional consultancy science has four elements: purpose, people, process, and product. Here the purpose is to provide an objective method for appraising development activities for their compliance with a no net loss objective, the people are the proponents and the regulators, the process involves both the use of HSM to structure the assessment and the negotiations among the parties, and the product is the decision with supporting documentation.

5.2 Scientific Defensibility Requirements

As Oreskes *et al.* (1994) clearly stated, "Verification and validation of numerical models of natural systems is impossible." The models are always incomplete representations of the natural systems and a variety of models can potentially produce similar predictions. The habitat suitability index model at the heart of HSM creates a numerical reflection of the observational data compiled in the habitat requirements databases (Lane *et al.* 1996 a,b,c). Thus the model provides its own initial level of confidence. As the model used is empirical, only empirical confirmation of the model's predictions is possible. Such confirmation requires one or both of the following:

- Comparative surveys across a wide range of habitat types in a several lakes, gathering both habitat and fish community metrics. Significant correlations between suitability indices computed using the habitat data and a range of fish community measures would provide a higher level of confidence.
- Replicated experimental studies of actual habitat alterations where both habitat and fish are assessed before and after the alterations, showing results consistent with HSM predictions would provide an even higher level of confidence.

Data collection for the first type of confirmation study has been conducted in the littoral zone at several locations in the Great Lakes (Ontario, Erie, and Georgian Bay in Lake Huron) with a range of habitat types at each location (Minns *et al.* 1994, Randall *et al.* 1996, Valere 1996). Analysis and modelling work will be reported in a separate publication (Minns *et al.* in prep).

5.3 Proponent-Regulator Interactions

Traditionally these interactions have been confrontational with both sides using non-quantitative rationales to support their positions. **Using a scientifically-defensible tool like HSM does not replace the proponent-regulator interactions, but has the potential to place discussions on a sounder, more objective footing.** Assumptions are laid out explicitly via the definition and the scenario files. The information supporting them has to be extensively documented and presented. Once both parties have agreed to use a quantitative method such as HSM, much of the potential for contention has been neutralized. Rather than disputing the relative merits of various habitats and actions subjectively, the parties must come to agreement about the method of valuing habitat units within the context of the fisheries objectives for that general area. Use of quantitative methods places an onus on both parties to present arguments and information that can withstand scrutiny.

The proponent is provided with an assessment tool that can be used to reduce the options for a development to those likely to produce a net gain of productive capacity and to refine the design of habitat modifications and enhancements. The proponent must provide a reasonable assessment of the existing habitats, an assessment that can withstand an audit. Use of a method like HSM should also decrease the volume of documentation required to describe the project and proposed changes to fish habitats. Much time can be saved as the proponent will try to avoid bringing forward proposals that clearly fail to satisfy the basic requirement for no net loss.

The regulator will still have to examine and judge the broader aspects and implications of a proposed development, where they lie beyond the current capability of methods like HSM. The regulator should be able to spend less time assessing the proposal. The regulatory agency benefits as it is now able to obtain an objective assessment of the net impact of each project when methods like HSM can be used.

Both parties can save much time and effort as the merits of projects can be assessed more quickly.

5.4 Future Plans and Extensions

At the time of writing, a number of future expansions of the HSM approach are being investigated:

- Further regional lake habitat requirements databases are being assembled for British Columbia and Yukon, and for the North encompassing NWT and Nunavut. These databases will allow lake-based applications of HSM to be implemented in those areas.
- A national location species list database is being completed and will be added to the software package. This database will allow the user to obtain a working freshwater fish species list for any tertiary watershed area in Canada.
- The Great Lakes lacustrine habitat requirements database is currently reassessed. Since the original databases were assembled in the mid-1990s, there has been an increase in the appearance of new fish habitat literature. The review will be used to update and revise the existing database. In addition, it has been apparent that vegetation cover was adequately assessed in the original literature survey. A more concerted effort to appraise the use of other forms of cover is under way and it is expected that the results will allow the range of categories to be expanded in a future revision of the database. Meanwhile, the current practice of inferring a vegetation cover equivalency for other types of cover will continue.
- An exploratory investigation of the potential to develop a stream-based application of HSM is under way in the Great Lakes basin with the cooperation of the Ontario unit of Fish Habitat Management. A stream habitat requirements database already exists for that area (Portt *et al.* 1999). Certain types of developments affecting streams such as highway culverts and stream realignments, may be highly suited to an HSM-based assessment.
- In each of the cases described above, complementary efforts to verification and calibration using field data sets will be undertaken to provide the supporting evidence necessary to justify the use of any model like HSM.

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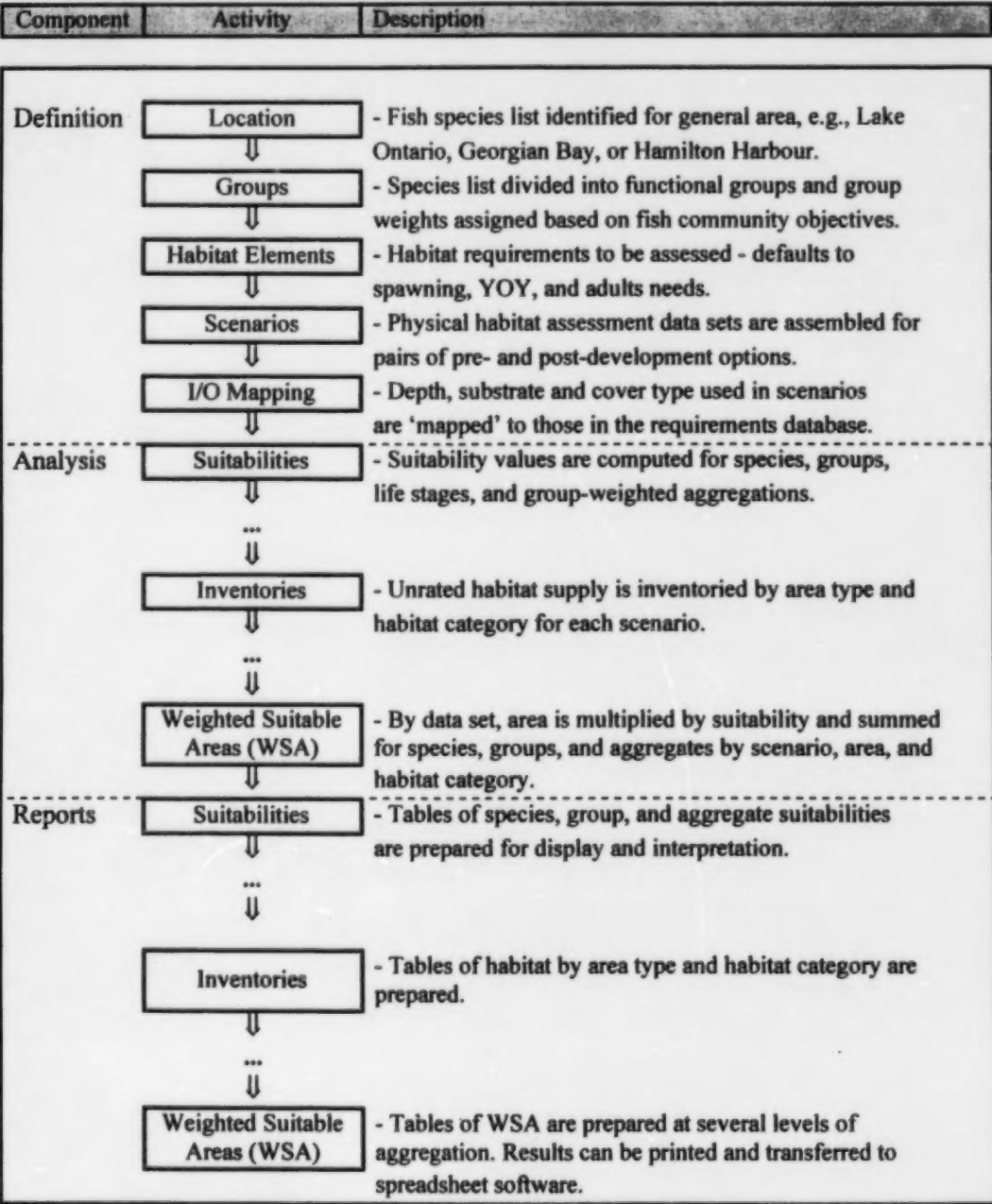
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Figure 2.1.1 A flow-chart showing the overall structure of HSM and the activities in the Definition, Analysis, and Reports components.



[...= intermediate steps]

Table 2.3.1 Sample hypothetical pre- and post-development scenario data files for use in an application of HSM.

[The first record contains the title for use in HSM. It and succeeding comment records begin with a semi-colon. Directive records describe the data records that follow and begin with an asterisk. Blank records are ignored and can be used to structure the file.]

Pre-development habitat scenario	Post-development habitat scenario
; OPTNPRE ; Option Pre-development * UnitType=Area * Units=m2 * Order=ID, Area, AreaType, Depth, Substrate, Vegetation 01, 200, LOSS, 0.0, SAND, NOVEG 02, 1800, LOSS, 0.0, BEDROCK, NOVEG 03, 300, LOSS, 0.5, BEDROCK, NOVEG 04, 120, LOSS, 0.5, SAND, NOVEG 05, 270, LOSS, 0.5, SAND, NOVEG 06, 1260, MODD, 0.5, BEDROCK, NOVEG 07, 140, MODD, 0.5, SAND, NOVEG 08, 320, MODD, 0.5, BEDROCK, NOVEG 09, 115, MODD, 0.5, SAND, NOVEG 10, 318, MODD, 0.5, SAND, NOVEG 11, 50, MODD, 1.0, SAND, NOVEG	; OPTNPOST ; Option Post-development * UnitType=Area * Units=m2 * Order=ID, Area, AreaType, Depth, Substrate, Vegetation 06, 1260, MODD, 0.5, COBBLE, NOVEG 07, 140, MODD, 0.5, COBBLE, NOVEG 08, 320, MODD, 0.5, ARMOUR, NOVEG 09, 115, MODD, 0.5, ARMOUR, NOVEG 10, 318, MODD, 0.5, ARMOUR, NOVEG 11, 50, MODD, 0.5, ARMCOB, NOVEG 12, 1000, COMC, 1.0, SILTYSAND, VEGGY

Table 2.3.2 Area categories for assessing net change of productivity of fish habitat after Minns (1995a, 1997). All areas in HSM scenarios should be assigned to one of these categories.

Code	Name	Description
LOSS	Loss	Destruction of habitat caused by the development activity, e.g., infilling.
MODD	Modified-Direct	Habitat directly modified by the development, e.g., changes in depth and substrate due to the addition of construction materials.
MODI	Modified-Indirect	Habitat indirectly modified as a result of the construction, e.g., the development creates a barrier which alters the sediment retention characteristics and reduces the wave/wind exposure of the site.
COMM	Compensation-Modified	Existing habitat deliberately modified outside the actual development site with the intention of increasing fish productivity to compensate for loss and/or decrease at the development site.
COMC	Compensation-Created	Habitat created where none existed with the intention of increasing fish productivity to compensate for loss and/or decrease at the development site.
UNCH	Unchanged	Habitat remaining unaltered by the development but included in the accounting of both PRE and POST scenarios or for total supply analysis.

Table 2.3.3 Alternate methods for assigning percentages to vegetation cover categories contingent on the type of information available.

Method	Cover Category Percentages			Total
	No Cover	Emergent (E)	Submergent (S)	
Categorical (P/A)				100
No Cover	100	0	0	
Emergent	0	100	0	
Submergent	0	0	100	
Proportion Additive	$100 - (\%E + \%S)$	$\%E$	$\%S$	100
Proportion Non-additive	$100 - \text{Max}(\%E, \%S)$	$\%E$	$\%S$	$100 - \text{Max}(\%E, \%S) + \%E + \%S = \text{TPN}$
Re-scaled	$[100 - \text{Max}(\%E, \%S) / \text{TPN}]$	$100 * \%E / \text{TPN}$	$100 * \%S / \text{TPN}$	100

Figure 2.4.1 A representation of the habitat suitability matrix (□) for a single species-life stage combination.

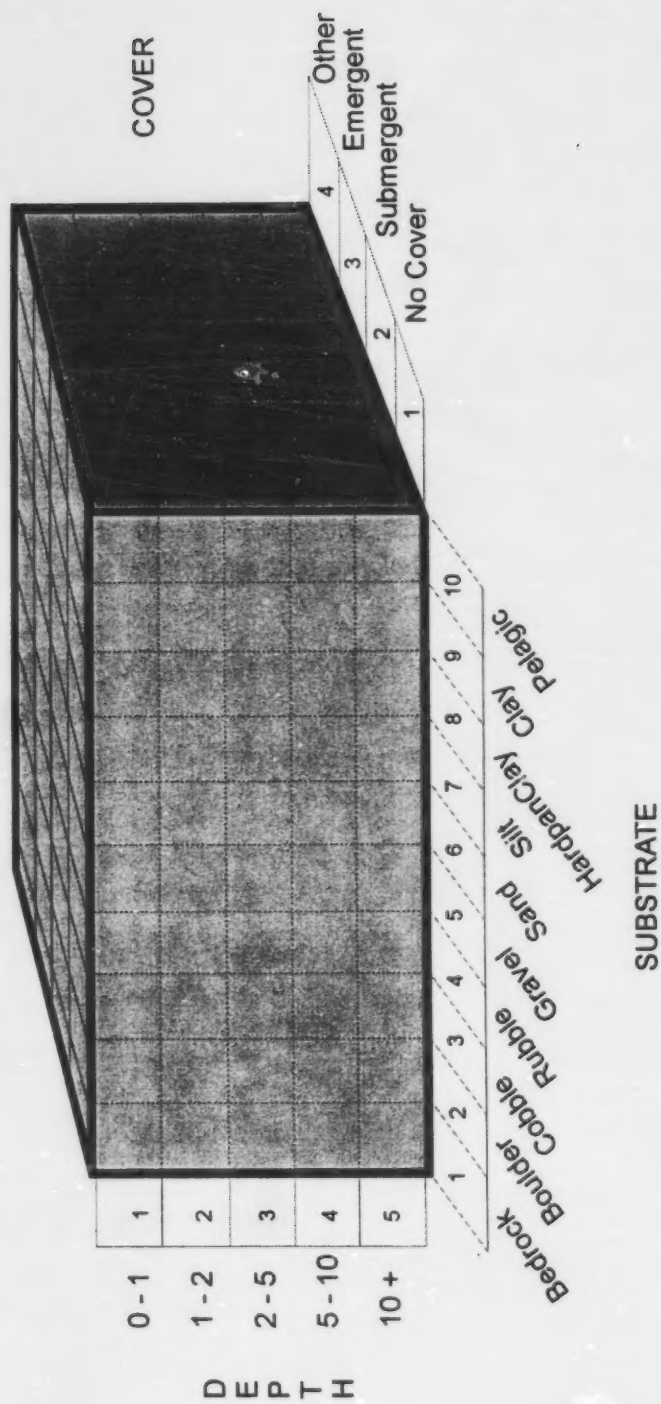


Table 2.4.1 How species level suitability matrices ($\square$) are pooled into fish group matrices.

Species	Weights	Fish Groups				
		A	B	C		M
1	1	$\square$	-	-	-	-
2	1	$\square$	-	-	-	-
3	1	-	-	$\square$	-	-
4	1	-	$\square$	-	-	-
5	1	-	-	$\square$	-	-
.	1	-	-	-	-	$\square$
.	1	-	-	-	$\square$	-
.	1	-	-	-	-	$\square$
N	1	-	-	$\square$	-	-
No. spp.	-	n_A	n_B	n_C		n_M
Group matrices		$\square$	$\square$	$\square$	$\square$	$\square$

Table 2.4.2 Assignment of weights among fish group and life stage suitability matrices ($\square$). The weights are proportions that sum to 1 on each axis and the sum of their cross-products also equals 1.

Fish Groups	Weights	Life Stages		
		Spawning	YOY	Adult
		W_A	W_B	W_C
A	W_A	$\square$	$\square$	$\square$
B	W_B	$\square$	$\square$	$\square$
C	W_C	$\square$	$\square$	$\square$
.	.	$\square$	$\square$	$\square$
M	W_M	$\square$	$\square$	$\square$
Sum	1			1



Table 2.4.1 How species level suitability matrices ($\square$) are pooled into fish group matrices.

Species	Weights	Fish Groups				
		A	B	C	..	M
1	1	$\square$	-	-	-	-
2	1	$\square$	-	-	-	-
3	1	-	-	$\square$	-	-
4	1	-	$\square$	-	-	-
5	1	-	-	$\square$	-	-
.	1	-	-	-	-	$\square$
.	1	-	-	-	$\square$	-
.	1	-	-	-	-	$\square$
N	1	-	-	$\square$	-	-
No. spp.	-	n_A	n_B	n_C		n_M
Group matrices		$\square$	$\square$	$\square$	$\square$	$\square$

Table 2.4.2 Assignment of weights among fish group and life stage suitability matrices ($\square$). The weights are proportions that sum to 1 on each axis and the sum of their cross-products also equals 1.

Fish Groups	Weights	Life Stages			Sum 1
		Spawning W_{SP}	YOY W_{YOY}	Adult W_{AD}	
A	W_A	$\square$	$\square$	$\square$	
B	W_B	$\square$	$\square$	$\square$	
C	W_C	$\square$	$\square$	$\square$	
.	.	$\square$	$\square$	$\square$	
M	W_M	$\square$	$\square$	$\square$	
Sum	1				1



Table 2.4.3 Inferred no cover preference levels based on the cross-matrix of emergent and submergent preferences for use when computing suitability matrices of Great Lakes basin lacustrine fishes.

Emergents	Submergents			
	Nil	Low	Medium	High
Nil	High	Medium	Low	Low
Low	Medium	Low	Low	Nil
Medium	Low	Low	Nil	Nil
High	Low	Nil	Nil	Nil

Table 2.4.3 Inferred no cover preference levels based on the cross-matrix of emergent and submergent preferences for use when computing suitability matrices of Great Lakes basin lacustrine fishes.

Emergents	Submergents			
	Nil	Low	Medium	High
Nil	High	Medium	Low	Low
Low	Medium	Low	Low	Nil
Medium	Low	Low	Nil	Nil
High	Low	Nil	Nil	Nil

Table 2.5.1 Sample input records of a hypothetical scenario pair for an exposed Lake Ontario shoreline site used as the basis for demonstrating sample output.

```

***
; PREOPTN
; Pre-development Option

* UnitType=Area
* Units=m2
* Order=ID, Area, AreaType, Depth, Substrate, Vegetation

01, 2100, LOSS, 0.0, SAND, NOVEG
02, 590, LOSS, 0.0, BEDROCK, NOVEG
03, 1580, MODD, 0.5, BEDROCK, NOVEG
04, 623, MODD, 0.5, SAND, NOVEG

***
; PSTOPTN
; Post-development Option

* UnitType=Area
* Units=m2
* Order=ID, Area, AreaType, Depth, Substrate, Vegetation

01, 50, MODD, 0.5, ARMCOB, NOVEG
02, 1400, MODD, 0.5, COBBLE, NOVEG
03, 753, MODD, 0.5, ARMOUR, NOVEG
04, 270, COMC, 1.0, SILTYSAND, VEGGY
***

```

Table 2.5.2 Summary of habitat criteria provided in a standard report for an application of HSM: A) Lake habitat types and weights, and B) Lake habitat classification.

A) Lake habitat types and weights:

	0.33	Adult habitat
Adult	0.33	Spawning habitat
Spawning	0.33	Nursery habitat
YOY		

B) Lake habitat classification:

	Depthzone	Z0_1	Z1_2	Z2_3	Z3-10	Z10+	Sand	Silt	Clay	Hardpan	Pelagic	No_use
Adult	Substrate	Bedrock	Boulder	Cobble	Rubble	Gravel						
	Vegetation	Submergent	Emergent	NoCover								
Spawning	Depthzone	Z0_1	Z1_2	Z2_3	Z3-10	Z10+						
	Substrate	Bedrock	Boulder	Cobble	Rubble	Gravel						
	Vegetation	Submergent	Emergent	NoCover								
YOY	Depthzone	Z0_1	Z1_2	Z2_3	Z3-10	Z10+						
	Substrate	Bedrock	Boulder	Cobble	Rubble	Gravel						
	Vegetation	Submergent	Emergent	NoCover								

Table 2.5.3 Lake habitat cross-classifications for linking reporting and scenario attribute classes to the internal classes for all three life stages in A) Depth zones, B) Substrates, and C) Vegetation cover.

A) Depth zones									
Depth zone	1.0	0.5	0.25	0.1	0.05	0.025	0.01	0.005	No. obs
1.0	X								
0.5		X							
0.25			X						
0.1				X					
0.05					X				
0.025						X			
0.01							X		
0.005								X	
No. obs	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	

B) Substrates									
Substrate	1.0	0.5	0.25	0.1	0.05	0.025	0.01	0.005	No. obs
1.0	X								
0.5		X							
0.25			X						
0.1				X					
0.05					X				
0.025						X			
0.01							X		
0.005								X	
No. obs	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	

C) Vegetation cover									
Vegetation cover	1.0	0.5	0.25	0.1	0.05	0.025	0.01	0.005	No. obs
1.0	X								
0.5		X							
0.25			X						
0.1				X					
0.05					X				
0.025						X			
0.01							X		
0.005								X	
No. obs	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	

Table 2.5.2 Summary of habitat criteria provided in a standard report for an application of HSM: A) Lake habitat types and weights, and B) Lake habitat classification.

A) Lake habitat types and weights

Name	Weight	Description
Adult	0.33	Adult habitat
Spawning	0.33	Spawning habitat
YOY	0.33	Nursery habitat

B) Lake habitat classification

Type	Variable	1	2	3	4	5	6	7	8	9	10	11
Adult	Depthzone	Z0_1	Z1_2	Z2_5	Z3-10	Z10+						
	Substrate	Bedrock	Boulder	Cobble	Rubble	Gravel	Sand	Silt	Clay	Hardpan	Pelagic	No use
	Vegetation	Submergent	Emergent	NoCover								
Spawning	Depthzone	Z0_1	Z1_2	Z2_5	Z3-10	Z10+						
	Substrate	Bedrock	Boulder	Cobble	Rubble	Gravel	Sand	Silt	Clay	Hardpan	Pelagic	No use
	Vegetation	Submergent	Emergent	NoCover								
YOY	Depthzone	Z0_1	Z1_2	Z2_5	Z3-10	Z10+						
	Substrate	Bedrock	Boulder	Cobble	Rubble	Gravel	Sand	Silt	Clay	Hardpan	Pelagic	No use
	Vegetation	Submergent	Emergent	NoCover								

Table 2.5.3 Lake habitat cross-classifications for linking reporting and scenario attribute classes to the internal classes for all three life stages in A) Depth zones, B) Substrates, and C) Vegetation cover.

A) Depth zones

Reporting:	0_1	1_2	2_5	5_10	10+
Z0_1	X				
Z1_2		X			
Z2_5			X		
Z5_10				X	
Z10+					X

Scenario:	0_1	1_2	2_5	5_10	10+
0.0	1.0				
0.5	1.0				
1.0	1.0				

C) Vegetation cover

reporting:	Submergent	Emergent	NoCover
Submergent	X		
Emergent		X	
NoCover			X

Scenario:	Submergent	Emergent	NoCover
NOVEG			1.0
VEGGY	0.25	0.25	0.5

B) Substrates

reporting:	Bedrock	Boulder	Cobble	Rubble	Gravel	Sand	Silt	Clay	Hardpan	Pelagic	No_use
Bedrock	X										
Boulder		X									
Cobble			X								
Rubble				X							
Gravel					X						
Sand						X					
Silt							X				
Clay								X			
Hardpan									X		
Pelagic										X	
No_use											X

Scenario:	Bedrock	Boulder	Cobble	Rubble	Gravel	Sand	Silt	Clay	Hardpan	Pelagic	No_use
ARMCOB		0.7	0.3								
ARMOUR	0.5	0.5									
BEDROCK	1.0										
COBBLE			1.0								
SAND						1.0	0.25				
SILTYSAND						0.75					

Table 2.5.4 Fish group names, weights, numbers of species overall and by life stage, and species lists for an application of HSM drawing from the Lake Ontario fish taxon.

Group ID	WARM P	WARM NP	COOL P	COOL NP	COLD P	COLD NP
Group name	Warmwater Piscivores	Warmwater Non-piscivores	Coolwater Piscivores	Coolwater Non-piscivores	Coldwater Piscivores	Coldwater Non-piscivores
Weight	0.167	0.167	0.167	0.167	0.167	0.167
Total spp.	4	29	7	42	9	14
Adult spp.	4	28	6	40	9	14
Spawning spp.	4	28	5	39	5	14
YOY spp.	4	27	5	40	7	14
Species	bowfin white bass smallmouth bass largemouth bass	gizzard shad central mudminnow quillback northern hog sucker goldfish common carp rosyface shiner spotfin shiner sand shiner bluntnose minnow fathead minnow central stoneroller yellow bullhead brown bullhead channel catfish stonecat tadpole madtom white perch rock bass pumpkinseed bluegill white crappie black crappie warmouth orangespotted sunfish freshwater drum carpXgoldfish rudd	longnose gar northern pike muskellunge grass pickerel tiger muskellunge American eel walleye	alewife rainbow smelt mooneye white sucker bigmouth buffalo silver redhorse shorthead redhorse greater redhorse northern redbelly dace finescale dace redside dace lake chub brassy minnow eastern silvery minnow river chub golden shiner pugnose shiner emerald shiner bridle shiner common shiner blackchin shiner blacknose shiner spottail shiner blacknose dace longnose dace creek chub fallfish banded killifish brook stickleback threespine stickleback ninespine stickleback yellow perch eastern sand darter rainbow darter Iowa darter fantail darter least darter johnny darter logperch channel darter tessellated darter brook silverside	chum salmon coho salmon chinook salmon rainbow trout Atlantic salmon brown trout brook trout lake trout burbot pearl dace trout-perch mottled sculpin slimy sculpin deepwater sculpin	lake sturgeon lake whitefish lake herring bloater kiyi shortnose cisco shortjaw cisco round whitefish longnose sucker

Table 2.5.5 Sample habitat supply area summary, m², by area type and habitat category for adult and spawning+YOY habitat classes. Using the input matrices, scenario areas are apportioned among the internal habitat classes.

Area type	Variable	Adult, Spawning and YOY		
		Class	PRE area	POST area
LOSS	Depth zones	0_1	2690.0	-
		1_2	-	-
		2_5	-	-
		5_10	-	-
		10+	-	-
	Substrate	Bedrock	2100.0	-
		Boulder	-	-
		Cobble	-	-
		Rubble	-	-
		Gravel	-	-
		Sand	590.0	-
		Silt	-	-
		Clay	-	-
		Hard-pan	-	-
		Pelagic	-	-
		No-use	-	-
	Vegetation cover	Submergent	-	-
		Emergent	-	-
		NoCover	2690.0	-
MODD	Depth zones	0_1	2203.0	2203.0
		1_2	-	-
		2_5	-	-
		5_10	-	-
		10+	-	-
	Substrate	Bedrock	1580.0	376.5
		Boulder	-	411.5
		Cobble	-	1415.0
		Rubble	-	-
		Gravel	-	-
		Sand	623.0	-
		Silt	-	-
		Clay	-	-
		Hard-pan	-	-
		Pelagic	-	-
		No-use	-	-
	Vegetation cover	Submergent	-	-
		Emergent	-	-
		NoCover	2203.0	2203.0
COMC	Depth zones	0_1	-	1000.0
		1_2	-	-
		2_5	-	-
		5_10	-	-
		10+	-	-
	Substrate	Bedrock	-	-
		Boulder	-	-
		Cobble	-	-
		Rubble	-	-
		Gravel	-	-
		Sand	-	750.0
		Silt	-	250.0
		Clay	-	-
		Hard-pan	-	-
		Pelagic	-	-
		No-use	-	-
	Vegetation cover	Submergent	-	250.0
		Emergent	-	250.0
		NoCover	-	500.0

Table 2.5.4 Fish group names, weights, numbers of species overall and by life stage, and species lists for an application of HSM drawing from the Lake Ontario fish taxon.

Group ID	WARM P	WARM NP	COOL P	COOL NP	COLD P	COLD NP
Group name	Warmwater Piscivores	Warmwater Non-piscivores	Coolwater Piscivores	Coolwater Non-piscivores	Coldwater Piscivores	Coldwater Non-piscivores
Weight	0.167	0.167	0.167	0.167	0.167	0.167
Total spp.	4	29	7	42	9	14
Adult spp.	4	28	6	40	9	14
Spawning spp.	4	28	5	39	5	14
YOY spp.	4	27	5	40	7	14
Species	bowfin white bass smallmouth bass largemouth bass	gizzard shad central mudminnow quillback northern hog sucker goldfish common carp rosyface shiner spotfin shiner sand shiner bluntnose minnow fathead minnow central stoneroller yellow bullhead brown bullhead channel catfish stonecat tadpole madtom white perch rock bass pumpkinseed bluegill white crappie black crappie warmouth orangespotted sunfish freshwater drum carpXgoldfish rudd	longnose gar northern pike muskellunge grass pickerel tiger muskellunge American eel walleye	alewife rainbow smelt mooneye white sucker bigmouth buffalo silver redhorse shorthead redhorse greater redhorse northern redbelly dace finescale dace redside dace lake chub brassy minnow eastern silvery minnow river chub golden shiner pugnose shiner emerald shiner bridle shiner common shiner blackchin shiner blacknose shiner spottail shiner blacknose dace longnose dace creek chub fallfish banded killifish brook stickleback threespine stickleback ninespine stickleback yellow perch eastern sand darter rainbow darter Iowa darter fantail darter least darter johnny darter logperch channel darter tessellated darter brook silverside	chum salmon coho salmon chinook salmon rainbow trout Atlantic salmon brown trout brook trout lake trout burbot longnose sucker	lake sturgeon lake whitefish lake herring bloaters kiyi shortnose cisco shortjaw cisco round whitefish longnose sucker pearl dace trout-perch mottled sculpin slimy sculpin deepwater sculpin

Table 2.5.5 Sample habitat supply area summary, m², by area type and habitat category for adult and spawning+YOY habitat classes. Using the input matrices, scenario areas are apportioned among the internal habitat classes.

Area type	Variable	Adult, Spawning and YOY		
		Class	PRE area	POST area
LOSS	Depth zones	0_1	2690.0	-
		1_2	-	-
		2_5	-	-
		5_10	-	-
		10+	-	-
	Substrate	Bedrock	2100.0	-
		Boulder	-	-
		Cobble	-	-
		Rubble	-	-
		Gravel	-	-
		Sand	590.0	-
		Silt	-	-
		Clay	-	-
		Hard-pan	-	-
		Pelagic	-	-
		No-use	-	-
	Vegetation cover	Submergent	-	-
		Emergent	-	-
		NoCover	2690.0	-
MODD	Depth zones	0_1	2203.0	2203.0
		1_2	-	-
		2_5	-	-
		5_10	-	-
		10+	-	-
	Substrate	Bedrock	1580.0	376.5
		Boulder	-	411.5
		Cobble	-	1415.0
		Rubble	-	-
		Gravel	-	-
		Sand	623.0	-
		Silt	-	-
		Clay	-	-
		Hard-pan	-	-
		Pelagic	-	-
		No-use	-	-
	Vegetation cover	Submergent	-	-
		Emergent	-	-
		NoCover	2203.0	2203.0
COMC	Depth zones	0_1	-	1000.0
		1_2	-	-
		2_5	-	-
		5_10	-	-
		10+	-	-
	Substrate	Bedrock	-	-
		Boulder	-	-
		Cobble	-	-
		Rubble	-	-
		Gravel	-	-
		Sand	-	750.0
		Silt	-	250.0
		Clay	-	-
		Hard-pan	-	-
		Pelagic	-	-
		No-use	-	-
	Vegetation cover	Submergent	-	250.0
		Emergent	-	250.0
		NoCover	-	500.0

Table 2.5.6 Weighted suitable areas (WSA) for the demonstration scenarios showing the format and organization of the report table. WSA, m², are the equivalent of the habitat area if habitat suitability were at the maximum.

Type	Group ID	Weights	Pre-scenario	Post-scenario
Adult	Warmwater Piscivores	0.17	695.3	724.4
	Warmwater Non-piscivores	0.17	705	956.3
	Coolwater Piscivores	0.17	75.6	468.8
	Coolwater Non-piscivores	0.17	1220.9	1120.5
	Coldwater Piscivores	0.17	32.8	13.5
	Coldwater Non-piscivores	0.17	97.8	65.2
Spawning	Warmwater Piscivores	0.17	872.8	674.4
	Warmwater Non-piscivores	0.17	1048.2	1082.7
	Coolwater Piscivores	0.17	318.7	339.1
	Coolwater Non-piscivores	0.17	888.2	843.8
	Coldwater Piscivores	0.17	432.4	329.9
	Coldwater Non-piscivores	0.17	729.9	837.9
YOY	Warmwater Piscivores	0.17	729.5	740.6
	Warmwater Non-piscivores	0.17	336.3	591.6
	Coolwater Piscivores	0.17	186.5	248.3
	Coolwater Non-piscivores	0.17	1044.8	725.3
	Coldwater Piscivores	0.17	1182.3	513.9
	Coldwater Non-piscivores	0.17	178.1	192.8
Weighted Sum				
	Adult	0.33	471.2	558.1
	Spawning	0.33	715	684.7
	YOY	0.33	609.6	502.1
Overall Sum			598.6	581.6

Table 2.6.1 Average suitability index values by thermal group of fish species for 150 unique combinations of depth, substrate, and vegetation cover classes, computed using HSM.

Depth	Substrate	Warmwater			Coolwater			Coldwater		
		No Cover	Emergent	Submergent	No Cover	Emergent	Submergent	No Cover	Emergent	Submergent
Z0_1	Bedrock	0.047	0.036	0.033	0.012	0.004	0.004	0.023	0.000	0.000
	Boulder	0.057	0.028	0.025	0.060	0.018	0.016	0.137	0.006	0.004
	Cobble	0.114	0.041	0.033	0.092	0.030	0.021	0.135	0.007	0.004
	Rubble	0.298	0.171	0.122	0.262	0.095	0.083	0.356	0.015	0.009
	Gravel	0.449	0.472	0.318	0.463	0.398	0.268	0.456	0.061	0.064
	Sand	0.461	0.958	0.710	0.480	0.647	0.527	0.378	0.074	0.063
	Silt	0.264	0.903	0.687	0.326	0.781	0.569	0.071	0.024	0.013
	Clay	0.061	0.151	0.143	0.038	0.103	0.142	0.015	0.000	0.000
	Hardpan	0.018	0.032	0.018	0.012	0.012	0.012	0.028	0.000	0.000
Z1_2	Pelagic	0.073	0.000	0.000	0.017	0.000	0.000	0.030	0.000	0.000
	Bedrock	0.047	0.036	0.033	0.012	0.004	0.004	0.023	0.000	0.000
	Boulder	0.057	0.028	0.025	0.060	0.018	0.016	0.104	0.006	0.004
	Cobble	0.088	0.041	0.033	0.059	0.027	0.018	0.068	0.007	0.004
	Rubble	0.238	0.171	0.122	0.147	0.071	0.058	0.212	0.015	0.009
	Gravel	0.328	0.472	0.318	0.350	0.312	0.181	0.342	0.026	0.013
	Sand	0.360	0.932	0.685	0.386	0.513	0.331	0.361	0.062	0.015
	Silt	0.264	0.877	0.661	0.295	0.656	0.382	0.076	0.024	0.013
	Clay	0.061	0.151	0.143	0.011	0.103	0.080	0.015	0.000	0.000
Z2_5	Hardpan	0.018	0.032	0.018	0.012	0.012	0.012	0.028	0.000	0.000
	Pelagic	0.073	0.000	0.000	0.017	0.000	0.000	0.030	0.000	0.000
	Bedrock	0.025	0.016	0.013	0.003	0.004	0.004	0.023	0.000	0.000
	Boulder	0.063	0.045	0.041	0.017	0.013	0.013	0.133	0.002	0.000
	Cobble	0.069	0.052	0.047	0.017	0.020	0.015	0.079	0.003	0.000
	Rubble	0.151	0.095	0.060	0.042	0.046	0.026	0.172	0.011	0.011
	Gravel	0.191	0.272	0.141	0.116	0.177	0.098	0.304	0.024	0.013
	Sand	0.193	0.348	0.220	0.116	0.235	0.159	0.350	0.025	0.015
	Silt	0.154	0.331	0.200	0.077	0.302	0.185	0.092	0.024	0.009
Z5-10	Clay	0.023	0.083	0.054	0.008	0.060	0.041	0.014	0.003	0.000
	Hardpan	0.031	0.045	0.031	0.012	0.012	0.012	0.029	0.000	0.000
	Pelagic	0.073	0.000	0.000	0.035	0.000	0.000	0.147	0.000	0.000
	Bedrock	0.024	0.011	0.011	0.003	0.004	0.004	0.174	0.000	0.000
	Boulder	0.062	0.037	0.037	0.006	0.007	0.007	0.212	0.006	0.004
	Cobble	0.065	0.040	0.040	0.007	0.009	0.008	0.220	0.007	0.004
	Rubble	0.115	0.041	0.041	0.025	0.029	0.015	0.244	0.013	0.014
	Gravel	0.140	0.129	0.049	0.080	0.079	0.047	0.194	0.011	0.015
	Sand	0.142	0.109	0.028	0.076	0.108	0.086	0.215	0.012	0.017
Z10+	Silt	0.118	0.094	0.014	0.033	0.132	0.113	0.303	0.011	0.009
	Clay	0.010	0.011	0.008	0.005	0.005	0.002	0.512	0.003	0.000
	Hardpan	0.024	0.024	0.024	0.009	0.009	0.009	0.148	0.000	0.000
	Pelagic	0.073	0.000	0.000	0.052	0.000	0.000	0.401	0.000	0.000
	Bedrock	0.024	0.011	0.011	0.003	0.004	0.004	0.174	0.000	0.000
	Boulder	0.031	0.010	0.010	0.005	0.005	0.005	0.209	0.007	0.006
	Cobble	0.035	0.014	0.014	0.005	0.007	0.006	0.218	0.008	0.006
	Rubble	0.037	0.014	0.014	0.017	0.027	0.012	0.245	0.012	0.014
	Gravel	0.037	0.029	0.023	0.067	0.065	0.034	0.199	0.014	0.014
	Sand	0.036	0.026	0.019	0.060	0.070	0.053	0.218	0.016	0.016
	Silt	0.025	0.019	0.014	0.018	0.095	0.081	0.309	0.015	0.009
	Clay	0.010	0.011	0.008	0.005	0.005	0.002	0.498	0.006	0.003
	Hardpan	0.006	0.006	0.006	0.008	0.008	0.008	0.148	0.000	0.000
	Pelagic	0.005	0.000	0.000	0.052	0.000	0.000	0.439	0.000	0.000

Figure 2.6.1 Mean habitat suitability index values among life stages (y-axis) versus depth (z-axis) and substrate classes (x-axis) for three thermal groupings of fish species (warm, cool and cold) across three cover classes (no cover, submergent, and emergent vegetation).

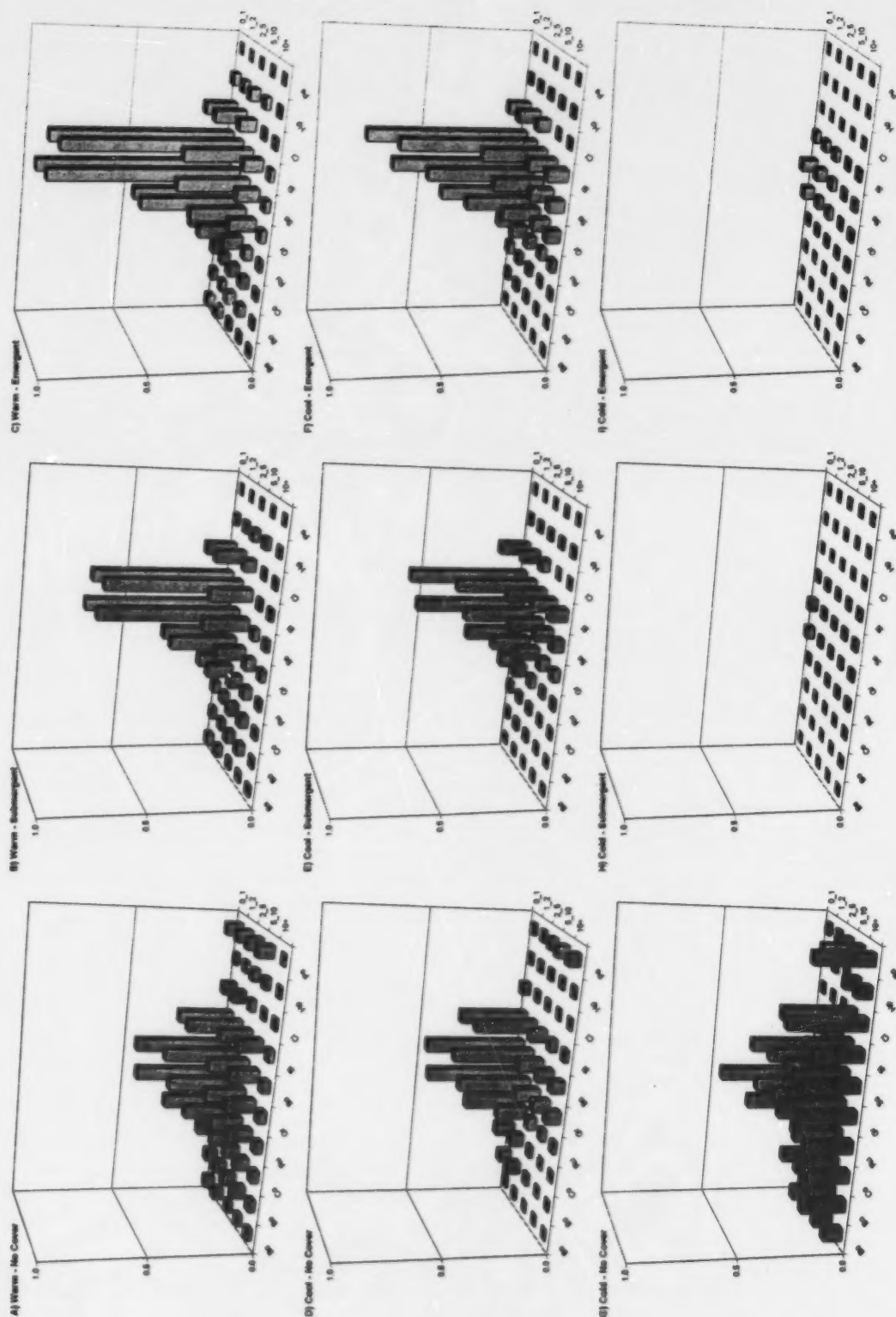


Table 2.6.2 Pearson correlations and their Bonferroni-adjusted significance levels among 18 habitat suitability indices representing all combinations of thermal, life stage, and trophic level groupings of the freshwater fishes occurring in lakes in the Great Lakes basin.

[illegible]

Bold - significant at $P=0.01$, *Italics* - significant at $P=0.05$ but >0.01 .

Figure 3.2.1 The framework for completing an application of the Habitat Suitability Matrix method. The numbers provide the logical order in which the steps are completed with sub-ordering indicated with lowercase letters.

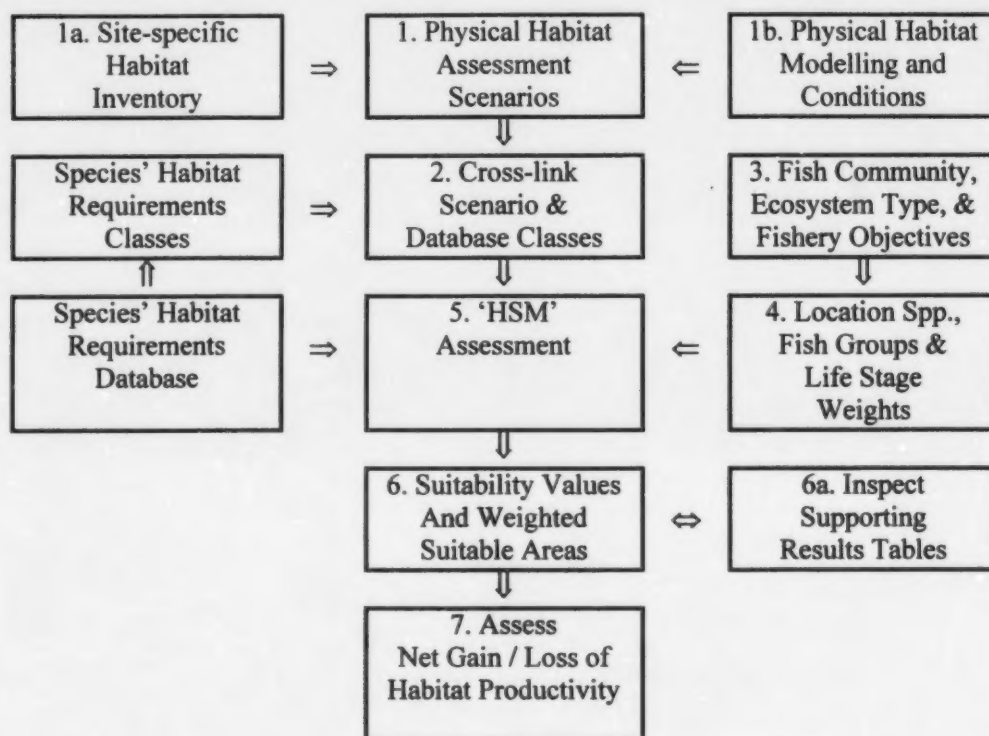


Figure 3.2.2 The fish habitat area categories illustrated for the construction of a solid pier on the shore of a lake.

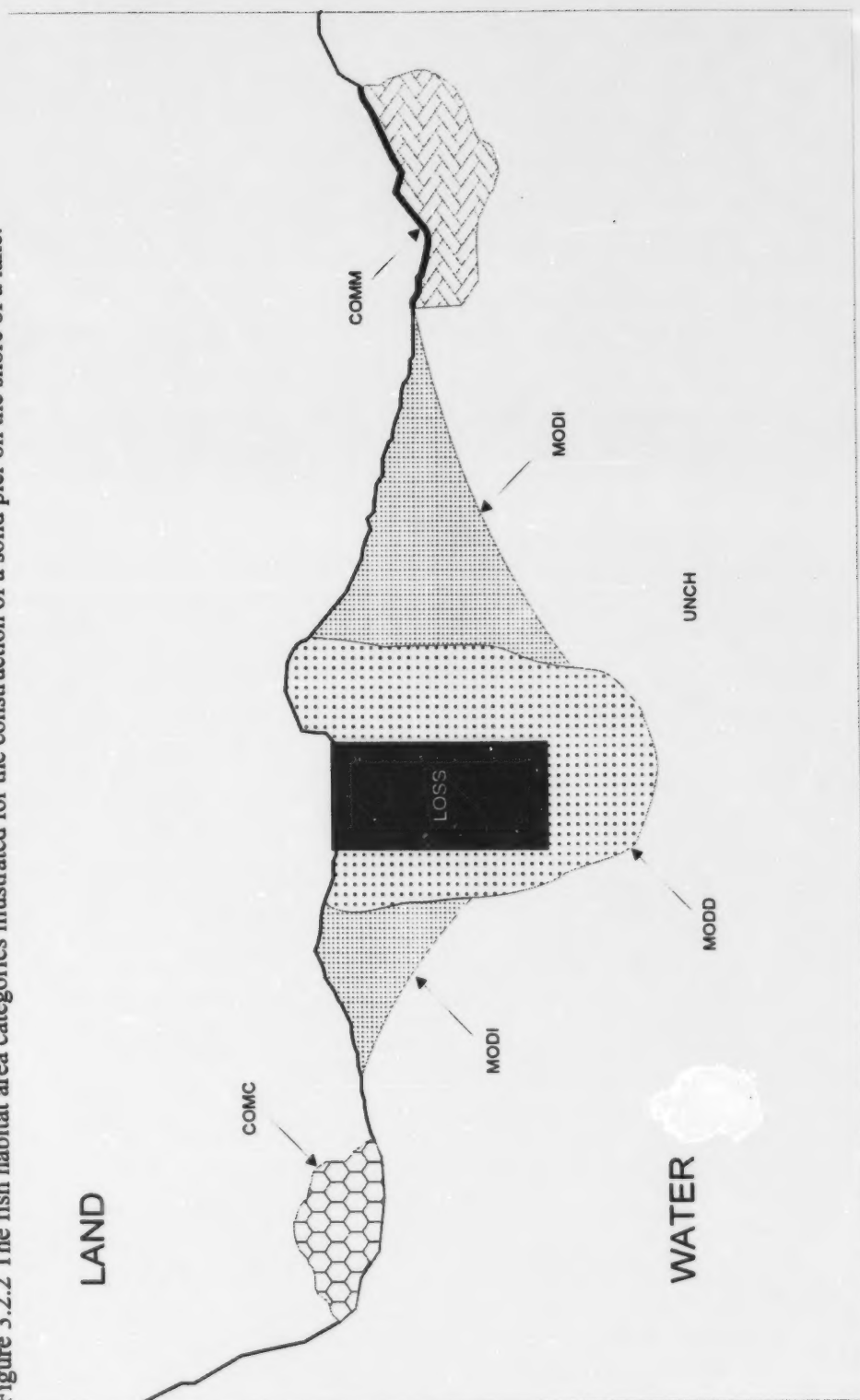


Figure 4.1.1 Illustration of case study 1, Brant Inn Node, A) prior to project and B) components of the preferred development option.

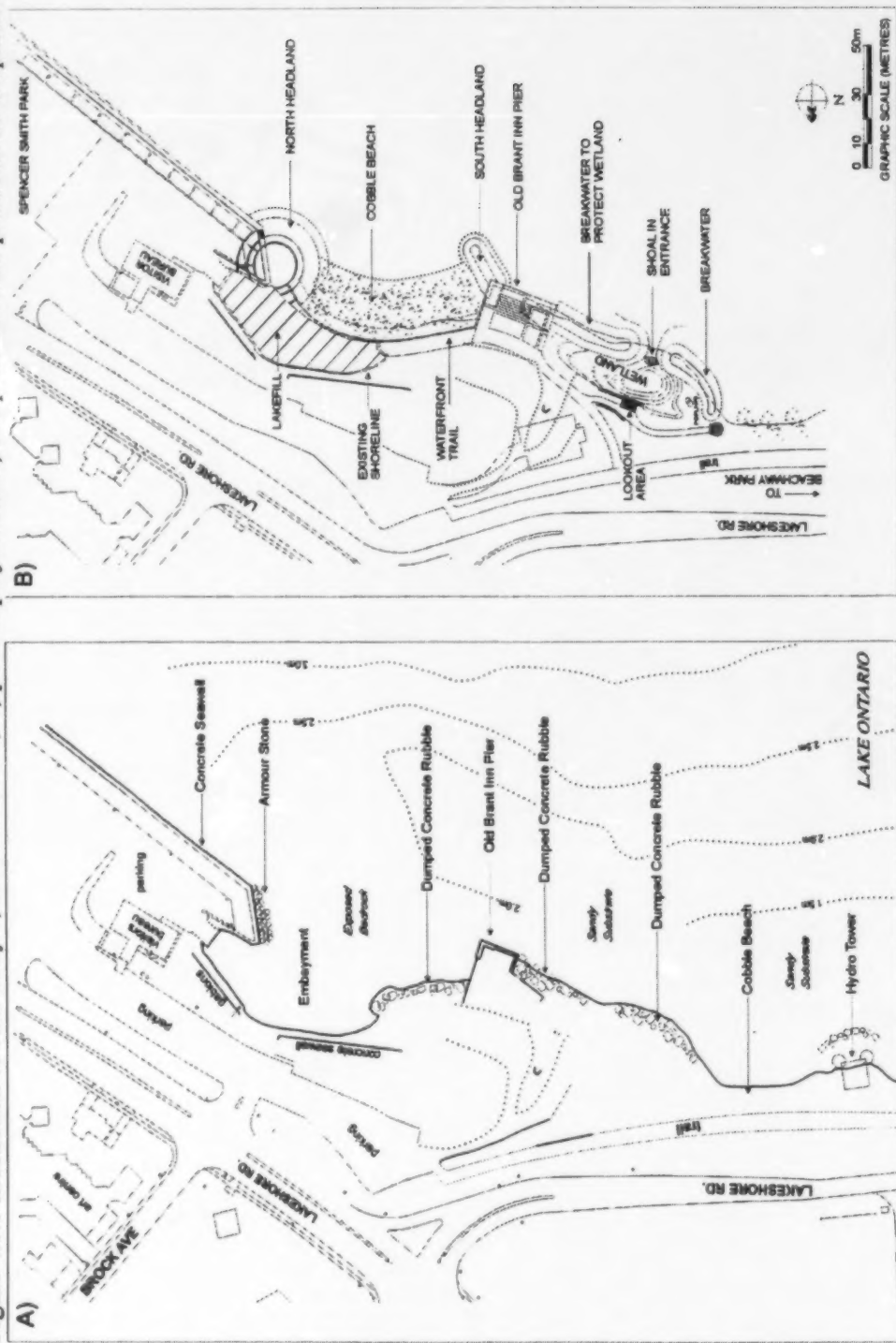


Figure 4.1.2 Bar-charts of A) pre-, post-, and net weighted suitable area (WSA) and B) area affected by type for the original 6 development options (option 0 was to do nothing) at Brant Inn Node on the Burlington waterfront of Lake Ontario.

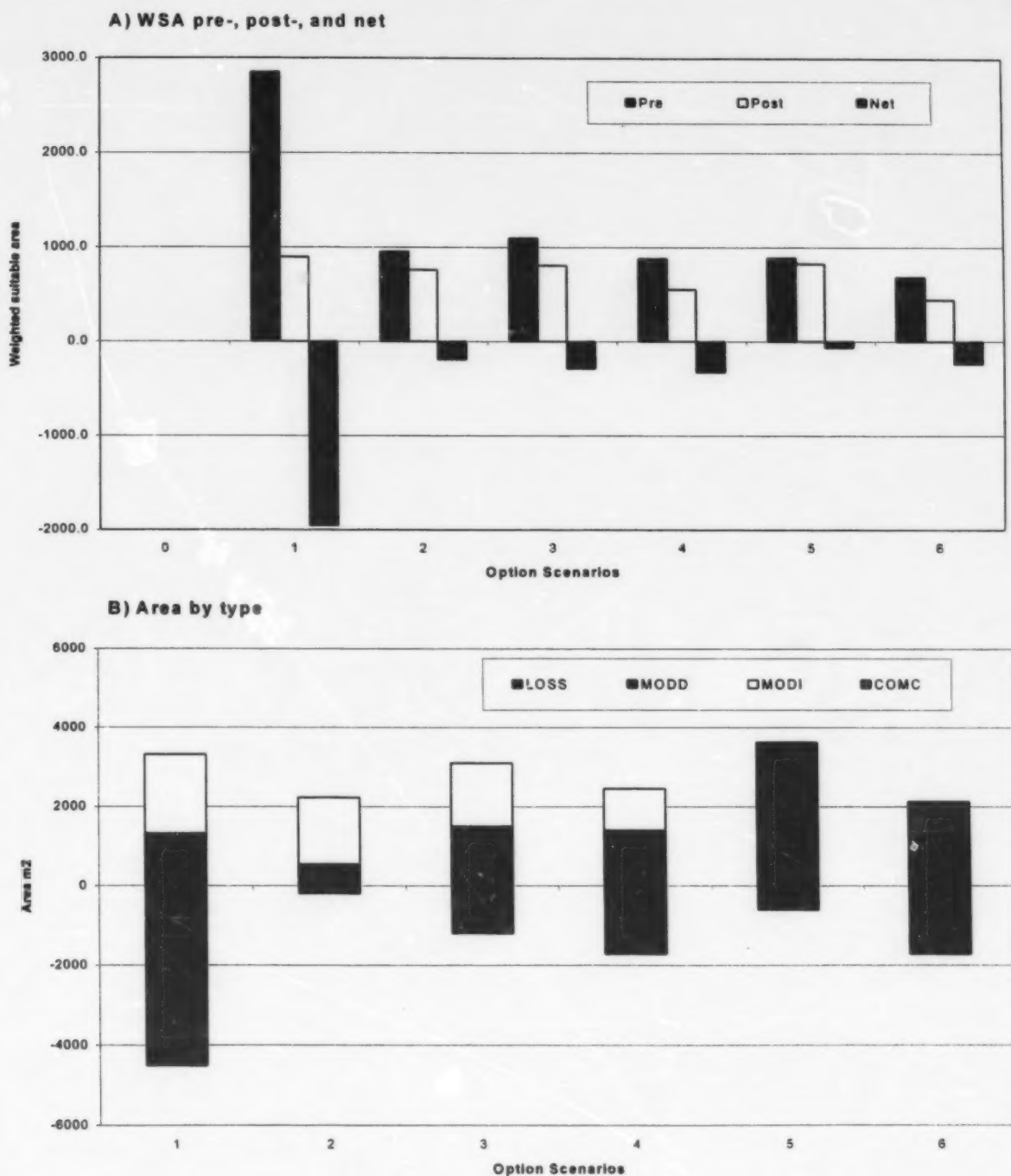


Table 4.1.2 The weighted suitable area (WSA) results for the final scenario of case study 1, the Brant Inn Node, application of HSM, showing pre- and post-development, net change, and percent change in WSA by life stage, fish groups and pooled groups, along with group weights.

Life Stage	Group	Weight	Pre-	Post-	Net Change	%
Adult	Warm Pisc	0.17	695.3	908.8	213.5	30.7
	Warm Non-Pisc	0.17	705.0	1255.7	550.7	78.1
	Cool Pisc	0.17	75.6	788.0	712.4	942.3
	Cool Non-Pisc	0.17	1220.9	1139.5	-81.4	-6.7
	Cold Pisc	0.17	32.8	12.6	-20.2	-61.6
	Cold Non-Pisc	0.17	89.7	69.9	-19.8	-22.1
Spawning	Warm Pisc	0.17	872.8	1228.5	355.7	40.8
	Warm Non-Pisc	0.17	1048.2	1404.7	356.5	34.0
	Cool Pisc	0.17	318.7	589.7	271.0	85.0
	Cool Non-Pisc	0.17	888.3	1222.8	334.5	37.7
	Cold Pisc	0.17	432.4	793.8	361.4	83.6
	Cold Non-Pisc	0.17	729.9	783.9	54.0	7.4
YOY	Warm Pisc	0.17	729.5	802.1	72.6	10.0
	Warm Non-Pisc	0.17	336.3	918.3	582.0	173.1
	Cool Pisc	0.17	186.5	228.8	42.3	22.7
	Cool Non-Pisc	0.17	1044.8	654.2	-390.6	-37.4
	Cold Pisc	0.17	1182.3	454.1	-728.2	-61.6
	Cold Non-Pisc	0.17	178.1	144.0	-34.1	-19.1
Pooled:						
Adult		0.33	469.9	695.7	225.8	48.1
Spawning		0.33	715.0	1003.9	288.9	40.4
YOY		0.33	609.6	533.6	-76.0	-12.5
Overall Sum			598.2	744.4	146.2	24.4

Figure 4.2.1 Illustration of the A) pre-development condition and B) post-development condition of case study 2, the Wallik property.

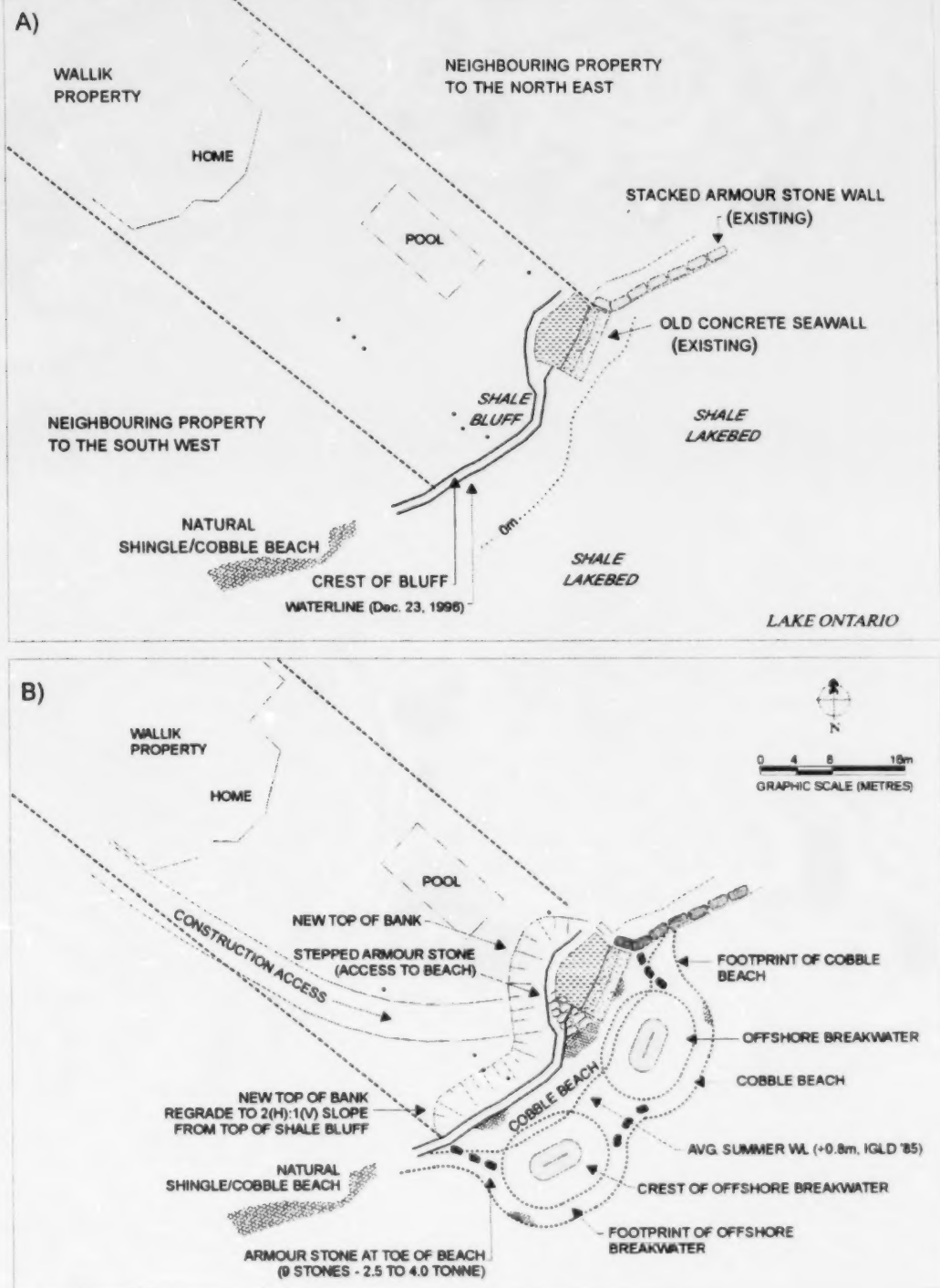


Table 4.2.1 The weighted suitable area (WSA) results for case study 2, the Wallik property, application of HSM, showing pre- and post- development, net change, and percent change in WSA by life stage, fish groups and pooled groups, along with group weights.

Life Stage	Group	Weight	Pre-	Post-	Net Change	%
Adult	Warm Pisc	0.17	0.0	38.7	38.7	+
	Warm Non-Pisc	0.17	2.1	58.3	56.2	2676.2
	Cool Pisc	0.17	0.0	12.6	12.6	+
	Cool Non-Pisc	0.17	0.7	78.0	77.3	11042.9
	Cold Pisc	0.17	0.0	1.9	1.9	+
	Cold Non-Pisc	0.17	2.6	5.1	2.5	96.2
Spawning	Warm Pisc	0.17	59.6	33.2	-26.4	-44.3
	Warm Non-Pisc	0.17	1.9	56.1	54.2	2852.6
	Cool Pisc	0.17	5.8	6.9	1.1	19.0
	Cool Non-Pisc	0.17	0	76.6	76.6	+
	Cold Pisc	0.17	18.7	84.9	66.2	354.0
	Cold Non-Pisc	0.17	0	77.5	77.5	+
YOY	Warm Pisc	0.17	29.2	40.1	10.9	37.3
	Warm Non-Pisc	0.17	0.0	9.7	9.7	+
	Cool Pisc	0.17	0.0	0.0	0.0	-
	Cool Non-Pisc	0.17	16.1	16.0	-0.1	-0.6
	Cold Pisc	0.17	0.0	65.5	65.5	+
	Cold Non-Pisc	0.17	0.0	11.7	11.7	+
Pooled:						
Adult		0.33	0.9	32.4	31.5	3500.0
Spawning		0.33	14.3	55.9	41.6	290.9
YOY		0.33	7.5	23.8	16.3	217.3
Overall Sum			7.6	37.4	29.8	392.1

Table 5.1.1 Derivation of eight principles of HSM method by comparison with the fundamental principles of cost-benefit analysis, after Griffin (1998).

Principle #	Wording	
	Cost-Benefit Analysis*	HSM Method**
One	Projects are deemed economically acceptable "... if the benefits to whomsoever they accrue are in excess of the estimated costs..."	+Analyses are deemed acceptable if the benefits in fish habitat productivity exceed the costs
Two	Welfare changes pertain to differences between with- and without-project scenarios	+Fish habitat productivity changes pertain to differences between pre- and post-development scenarios
Three	Cost measurement is founded on social opportunity costs	+Measures of potential habitat productivity provide the reference currency for analyses
Four	Producer benefits are to be measured as producer surplus changes	+/?Fish are the beneficiary in both instances and the benefits are the marginal changes in fish habitat productivity
Five	Consumer benefits are to be measured as consumer surplus changes	
Six	Zero-sum transfers of benefits or costs are to be ignored	-All habitats and their productivities affected by the project are included in the analysis
Seven	Temporal aggregation employs discounting	?Discounting is not considered in the current version
Eight	Unmonetized welfare changes are to be disclosed	+Other issues and factors not expressed in the analysis should be captured in the final decision-making

* Exact wording from section 7 of Griffin (1998)

** + implies agreement, - disagreement, and ? incomplete in current version

Appendix A: Adjusting analysis for changes in wave exposure on the Great Lakes.

Introduction

Cumulative experience with a range of development projects affecting littoral habitats in the Great Lakes and other large Ontario inland lakes indicated an anomaly in the case of breakwalls installed on shores with high wave exposure. The breakwalls are usually installed as part of a marina development or to provide some relief for the existing shoreline. They are usually designed to provide for some level of water exchange/circulation minimizing the potential for stagnation in the lee of the breakwall. The breakwall will substantially reduce the wave exposure and physical disturbance of fish habitats in the lee of the structure. The basic configuration of the Habitat Suitability Matrix (HSM) model does not reflect this effect which is generally noted to be associated with increasing fish abundance. The HSM model only considers combinations of depth, substrate and cover. These values may not change in indirectly modified areas (MODI) in the lee of the breakwall and hence the weighted suitable area values for those habitat areas would be unchanged between pre- and post-development scenarios. As a result the proponent can face great difficulty trying to devise a package of habitat modifications and compensation to offset the losses associated with the breakwall structure itself.

The HSM method does allow for the use of an auxiliary variable, the Condition Index, in situations where additional habitat conditions change. The purpose of the analyses reported here was to derive estimates from field data of the expected change in fish community measures arising from changes in wave exposure. These estimates might then be used to derive a simple method for estimating Condition Indices for areas in the lee of a breakwall that are either modified indirectly or through compensation.

Materials and Methods

The data used to examine the effect of wave exposure on fish community metrics was drawn from the Great Lakes nearshore electrofishing transect database (Valere 1966). Using a standard 100 metre transect along the 1.5 metre contour, a wide range of shore habitats have been assessed in lakes Ontario and Erie and in Georgian Bay. The biomass and number of fish caught are recorded by species for each transect sample. For this analysis, data from Hamilton Harbour were excluded as previous analyses have shown that the fish community metrics are lower there compared to other sites due to factors other than physical habitat (Minns *et al.* 1994). In addition, data collected at a series of harbours and marinas on lakes Ontario and Erie were also excluded from the analysis to ensure that the adjustment factors for exposure were based on natural habitat conditions rather than any factors present at harbours and marinas apart from wave exposure changes. This left a data set of 501 transect samples.

Four measures were derived for each transect sample: species richness, biomass, number per unit effort, and the adjusted Index of Biotic Integrity (IBI) which is indicative of the biodiversity at each site. These are measures previously shown to be key indicators for the fish community in the littoral zone of the Great Lakes (Randall *et al.* 1996, Minns *et al.* 1994.). To derive a single metric representative of these four measures, a principal components analysis (PCA) was performed and the first factor score used as a fish community metric. The biomass and numbers measures were transformed by taking $\log_{10}(X+1)$ to produce distributions more closely approximating normal.

Maximum effective fetch was used as an indicator of the wave exposure at each transect location (Thomas 1986). Fetch has been previously been shown to be an

important predictor of changes in fish community metrics (Randall *et al.* 1996). Effective fetch (km) was computed using the formula of Scheffer *et al.* (1992) from raw fetch distances measured for 16 compass bearings using a geographical information system and the maximum at each site selected. For statistical analysis, a $\log_{10}$ transformation of the fetch values was used to ensure that the fetch variable approximated normal distribution.

Results

The PCA analysis produced a single factor with an eigenvalue greater than 1, accounting for 61.6 percent of variability (Table A1). The factor scores for the first component were taken as composite measures for the four fish community metrics. Each of the constituent measures was highly correlated with the metric (Figure A1).

A linear regression of the fish community factor score as a function of $\log_{10}$ maximum effective fetch was highly significant ($P < 0.01$):

$$\text{Factor} = 0.630 - 0.159 \log_{10} \text{Max. Effective Fetch} \quad (r = 0.476, F=145.9, n=501)$$

However, the result showed considerable variability around the regression line (Figure A2). There appeared to be a step drop in the level of the fish metric beyond a certain level of maximum effective fetch.

A simpler analysis using K-means clustering supported the idea of dividing the data into two clusters with a cut-off on the fetch axis at 10 km (Tables A2 and A3). The ANOVAs for separation of factor and fetch data were highly significant (Table A2). If the fish metric mean of the low fetch cluster is used as a reference point, the high fetch cluster's fish metric mean has a ratio of 0.64, meaning fish community measures at high fetch sites are approximately 64 percent of those at low fetch sites (based on Table A3).

Discussion and Recommendation

The results obtained here are consistent with those obtained in previous reported analyses. They provide a basis for modifying scenarios used with the Habitat Suitability Matrix method to assess net change at wave-exposed sites on the Great Lakes, and in other large Ontario lakes such as Simcoe, Nipigon, Nipissing, etc., where wind-driven wave processes are a major forcing effect on exposed shorelines.

By default the Condition Index for all habitat patches affected by a marina development are given a value of 1 (Table A4). Areas of loss (LOSS) keep this default condition as losses are always charged at the maximum rate for net change calculations. Areas of direct modification (MODD) and any modified compensation area (COMM) on the windward side due to the footprint of the breakwall should be assigned a value of 0.64 in both pre- and post-scenarios to reflect the continuing presence of wave exposure reducing the value of the habitat to fish. The slope areas on the leeward side of the breakwall (also MODD) and areas in the lee of the breakwall but not on the footprint itself are considered to be indirectly modified (MODI) are assigned the high exposure value in the pre-development scenario (0.64) and the low exposure value in the post-development scenario (1.00) to reflect the change in habitat suitability induced by reducing the wave exposure. In straightforward situations, it should be simple for proponent and regulator to agree on the extent of this MODI area. Otherwise, an exact analysis of fetch changes will be necessary to delimit the MODI area where maximum effective fetch shifts from > 10 km to < 10 km. Any compensation areas in the lee of the breakwall where habitats are modified to enhance productivity (COMM), i.e. through the addition of shallow cribs supporting submergent or emergent vegetation or of other cover

types, can be treated as MODI areas. As created compensation areas (COMC) are expected to make a positive contribution to the net change balance as long as they are positioned in the lee of the breakwall, a Condition Index of 1.00 should be assigned. The results of analyses with and without the application of the Condition Index should be reported as part of the habitat assessment under Section 35 of the Fisheries Act.

This approach reflects the superficial situation seen around breakwalls, although whether breakwalls, like reefs, enhance habitat productivity or merely act as attractants and concentrators for fish from surrounding areas is unknown. This situation prevails, especially in marine ecosystems, despite many decades of research. Should research subsequently reveal that the main impact is as an attractant, the rationale for making the adjustments in Condition Index laid out for HSM analyses of breakwalls would be greatly weakened and the indices may no longer be applicable. The contribution of habitats to the natural productivity of fish communities must remain the primary basis for assessing net gain or loss of productive capacity.

Table A1 Results of principle components analysis to obtain a factor representative of several fish community metrics using 501 electrofishing samples from various shore locations in the lower Great Lakes.

Factor	1	2	3	4
Eigenvalue	2.464	0.939	0.333	0.264
Coefficients				
Variables				
Log ₁₀ Biomass	0.831			
Log ₁₀ Numbers	0.856			
No. species	0.884			
Adjusted IBI	0.509			

Table A2 Results of the analyses of variance for the K-means clustering.

Variable	Between SS	df	Within SS	df	Total
Log Max EF	154.31	1	47.56	499	1619.02
Fish factor	3.33	1	19.41	499	85.65
Total	157.64	2	66.97		

Table A3 The results of the K-means clustering of sample data (Figure A2) using log₁₀ maximum effective fetch and the standardized fish metric.

Cluster	Variable	Minimum	Mean	Maximum	Std. Dev.	N
1	Max. effective fetch	-0.42	0.32	1.00	0.32	398
	Fish metric	0.00	0.58	1.00	0.18	
2	Max. effective fetch	1.00	1.70	2.04	0.26	103
	Fish metric	0.00	0.37	0.91	0.25	

Table A4 Rules for assigning Condition Index values in analyses of breakwall projects on highly exposed shorelines of large lakes.

Area type	Pre-development scenario	Post-development scenario
LOSS	1.00	n.a.
MODD windward	0.64	0.64
MODD leeward	0.64	1.00
MODI leeward	0.64	1.00
COMM leeward	0.64	1.00
COMM windward	0.64	0.64
COMC	n.a.	1.00



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Table A2 Results of the analyses of variance for the K-means clustering.

Variable	Between SS	df	Within SS	df	F-ratio
Log Max EF	154.31	1	47.56	499	1619.02
Fish factor	3.33	1	19.41	499	85.65
Total	157.64	2	66.97		

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COMM leeward	0.64	1.00
COMM windward	0.64	0.64
COMC	n.a.	1.00

Figure A1 Plots showing the relationship between the set of individual fish metrics (number of species, log numbers, log biomass and adjusted IBI) and the standard factor score obtained with the first principal component.

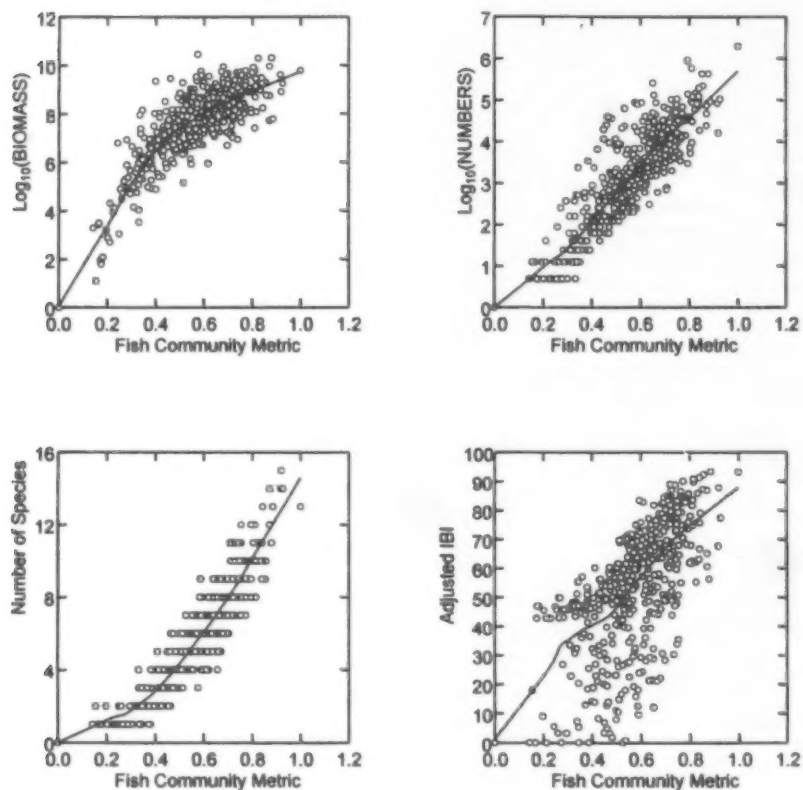
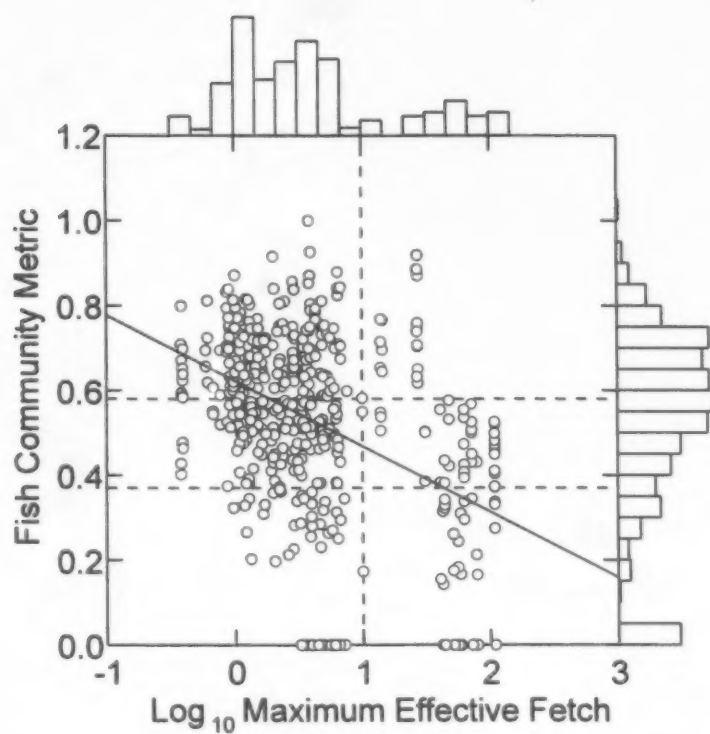


Figure A2 Plot of the fish community metric based on the F-CA versus $\log_{10}$ maximum effective fetch, km, for 501 electrofishing samples. The edge bar diagrams show the frequency distributions for the two data variables and the dashed lines show the mid-points for the two clusters and the fetch cut-off for the two clusters.



Appendix B: Pre- and post-development scenario habitat data sets for the two case studies presented in section 4. Area types are described in Table 2.3.2.

Brant Inn Node	Pre-development habitat scenario	Post-development habitat scenario
; OPTNPRE ; Option Pre-development * UnitType=Area * Units=m2 * Order=ID, Area, AreaType, Depth, Substrate, Vegetation 01, 200, LOSS, 0.0, SAND, NOVEG 02, 1800, LOSS, 0.0, BEDROCK, NOVEG 03, 300, LOSS, 0.5, BEDROCK, NOVEG 04, 120, LOSS, 0.5, SAND, NOVEG 05, 270, LOSS, 0.5, SAND, NOVEG 06, 1260, MODD, 0.5, BEDROCK, NOVEG 07, 140, MODD, 0.5, SAND, NOVEG 08, 320, MODD, 0.5, BEDROCK, NOVEG 09, 115, MODD, 0.5, SAND, NOVEG 10, 318, MODD, 0.5, SAND, NOVEG 11, 50, MODD, 1.0, SAND, NOVEG	; OPTNPOST ; Option Post-development * UnitType=Area * Units=m2 * Order=ID, Area, AreaType, Depth, Substrate, Vegetation 06, 1260, MODD, 0.5, COBBLE, NOVEG 07, 140, MODD, 0.5, COBBLE, NOVEG 08, 320, MODD, 0.5, ARMOUR, NOVEG 09, 115, MODD, 0.5, ARMOUR, NOVEG 10, 318, MODD, 0.5, ARMOUR, NOVEG 11, 50, MODD, 0.5, ARMCOB, NOVEG 12, 1000, COMC, 1.0, SILTYSAND, VEGGY	
Wallik property ; WALLPRE ; Case 2 Pre High Water * UnitType=Area * Units=m2 * Order=ID, Area, AreaType, Depth, Substrate, Vegetation 01, 14, LOSS, 1.0, BEDROCK, NOVEG 02, 46, LOSS, 1.0, BEDROCK, NOVEG 03, 17, LOSS, 1.0, BEDROCK, NOVEG 04, 40, MODD, 1.0, BEDROCK, NOVEG 05, 130, MODD, 1.0, BEDROCK, NOVEG 06, 80, MODI, 1.0, BEDROCK, NOVEG	; WALLPST ; Case 2 Post High Water * UnitType=Area * Units=m2 * Order=ID, Area, AreaType, Depth, Substrate, Vegetation 04, 40, MODD, 1.0, BOULDER, NOVEG 05, 130, MODD, 1.0, COBBLE, NOVEG 06, 80, MODI, 1.0, COBBLE, NOVEG	